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SOIL MOISTURE INDICES AND SNOWFALL CORRELATION TO SNOWMELT RUNOFF IN CENTRAL ALBERTA

by

© T. P. S. SANDHU

A THESIS
SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH
IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE
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FACULTY OF GRADUATE STUDIES AND RESEARCH

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research for acceptance, a thesis entitled "SOIL MOISTURE INDICES AND SNOWFALL CORRELATION TO SNOWMELT RUNOFF IN CENTRAL ALBERTA", submitted by Tirath Pal Singh Sandhu in partial fulfilment of the requirements for the degree of Master of Science in Hydraulics and Hydrology.

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ABSTRACT

The snowmelt runoff is a function of the soil moisture conditions before winter, snowfall water equivalent and rainfall during the snowmelt period. The study presented in this thesis is an attempt to analyze and correlate the snowmelt runoff and its variables using the statistical records. The study is confined to the central Alberta region and the five selected basins; the Blindman River, Upper Paddle River, Whitemud Creek, Swan River and the West Prairie River Basin.

The soil moisture conditions before freeze-up were assessed on the basis of base flow storage, antecedent precipitation index and the basin recharge coefficient. The base flow storage was determined from flow in the streams in late fall and the base flow recession characteristics of the basins. The antecedent precipitation index was obtained by weighting the summer and fall precipitation values. The basin recharge coefficient was assumed to be represented by the percentage of the precipitation retained in the basin.

The snowfall water equivalent in winter was calculated by weighting the recorded precipitation values using the Thiessen Polygon method and separation of the snowfall and rainfall events on the basis of temperature and published snowfall summaries for the climatological stations. For snowmelt runoff, the snowmelt period was defined for each year on the basis of temperature, snowcover on the ground and the rainfall events. The total volume of snowmelt runoff was determined by hydrographic analysis using the snowmelt recession curves and separation of rainfall runoff from snowfall runoff.

The correlation of the snowmelt variables was obtained by alternative graphical means assuming the variables as independent or dependent. To simplify the application, curves for 4 to 8 inches of snowfall water equivalent were interpolated for the correlations. It was observed that a definite correlation exists between the snowmelt runoff, snowfall water equivalent and soil moisture conditions when the base flow storage and antecedent precipitation index are used as indices of soil moisture. A definite correlation could not be established with basin recharge coefficient as an index. The variability of results reflected that the basin topography and location also influence the timing of snowmelt runoff. The rainfall runoff effect on the snowmelt runoff volume is not appreciable.

The correlation of the snowmelt runoff and its variables obtained in this study can be useful in the estimation of spring runoff, if soil moisture conditions before freeze-up and snowfall amounts are known. It can be applied in designing the capacity of the water supply and flood control reservoirs and planning of operations for reservoir regulation.

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LIST OF SYMBOLS

Symbol	Definition
API	Antecedent Precipitation Index
BRC	Basin Recharge Coefficient
Q_o, Q, Q'	Daily Flows in Cubic feet per second at time t_o, t and t' respectively
W.E.	Water Equivalent in inches
P	Precipitation in inches
R	Rainfall in inches
S	Snowfall W.E. in inches
T	Mean Daily Temperature in °F
P_m, P_{ju}, P_j, P_a, P_s, P_o etc.	Recorded Monthly Rainfall in inches for the months of May, June, July, August, September and October respectively
S_r	Snowmelt Runoff in inches
R_o	Monthly Runoff for October in inches
S_b	Base Flow Storage in inches
K, K_r	Daily Runoff Recession Coefficients
K_{rb}	Daily Runoff Base Flow Recession Coefficient
a,b,c,d,e,f, etc	Monthly API Constants
$\Sigma K'$	Sum of Monthly API Constants
k	Daily API Constant

CHAPTER I

INTRODUCTION

Project Outline

The main objective of the study is to analyze the spring snowmelt runoff in Central Alberta, in relation to winter snowfall and soil saturation conditions before freeze-up and derive any correlations which exist between snowmelt runoff and these variables. In general, the study included the following.

1. Selection of basins in Central Alberta, north of the City of Red Deer, located in between 52° and 56° latitudes and having sufficient climatological and hydrometric information for analysis.
2. Determination of snowfall accumulation for the winter season from freeze-up to thawing.
3. Assessment of soil saturation conditions in the form of Base Flow storage and Antecedent Precipitation Indices before winter freeze-up.
4. Defining snowmelt runoff periods, determining snowmelt runoff recession at the end of such periods and evaluating the total volume of snowmelt runoff in spring.
5. Graphical correlation of snowmelt runoff, precipitation and soil moisture conditions in the selected basins.

Importance of Snowmelt Runoff Prediction

Runoff from snowmelt forms a major portion of the total annual runoff in Alberta. The snow is a vital source of water supply in this cold and temperate climatic region with temperatures varying from -40°F to + 40°F from one season to another season. About 80 - 85 % of the streamflow in the major river systems and water stored in dugouts and sloughs originates from the snowpack (Gray, 1968). The water surpluses are available in the spring months during the snowmelt period and are reflected by the early spring peaks in comparison to low summer and winter flows in the streams. Implications of these flow variations are two fold. The snowmelt water appears in the streams for a short duration whereas the water supply demand is throughout the year. The spring snowmelt peak can cause extensive damage to agricultural and urban areas. Investigations for effective control and optimum development of the water resource in the central areas of Alberta, must take into account the contribution of spring season runoff from snowmelt and its efficient utilization in periods of shortage.

The snowmelt process in which the snowpack gains heat, increases in density and finally releases water, is complex and is not only related to temperature changes but also to soil moisture conditions. Soil saturation before winter is difficult to measure in the field for large watersheds. Studies conducted on Spring Creek Basin, northwest of Edmonton (Holecek, 1971) indicate in one year with a recorded snowfall water equivalent of 6½ inches, 0.17 inches of runoff occurred, with a comparable water equivalent in another year, the volume of runoff was 2.8 inches. Understanding of the hydrologic behaviour of drainage basins and the processes which cause such variations in runoff is important.

Prediction of snowmelt runoff volumes is important for seasonal water yield and rate of runoff forecasting. From water supply point of view, accurate forecast of the total volume may be the main interest in comparison to the peak rates of flow. On the other hand to achieve highest accuracy in flood forecasting, although maximum flow is a major consideration, information on the snowmelt runoff volume is necessary to design the capacity of flood control reservoirs and planning of operations for reservoir regulation. Long range forecasts of seasonal runoff volume made in advance of the runoff period can aid in developing reservoir operating rules to meet all project requirements and assume full use of reservoir storage on the basis of projected inflows on a seasonal basis. Modeling Techniques have been used for such forecasting (Nelson, 1969). The medium range forecasts, 5 to 30 days in advance, can be useful for daily operation of the reservoir.

Study Area

1. General Features

The Central Alberta area referred to in this study is the area bounded by 52° latitude on the south, 56° latitude on the north and the provincial boundaries on the east and west, excluding the Rocky Mountains Region. As shown on Plate No. 1, the area is located north of the City of Red Deer and south of the Lesser Slave Lake. All basins selected for analysis are situated in this area. The general criteria for delineating the boundaries is based on three factors;

i) Effect of Chinooks

ii) Effect of Elevation Changes

iii) Physiographic Homogeneity of the Region.

The southern part of Alberta is affected by chinooks which are warm, dry foehn-like winds of moderately high velocity. Chinooks can bring abrupt temperature changes and appreciable melting and evaporation of the snowpack may occur at different times throughout the winter and thus the pack may completely disappear. Runoff occurrence in chinook areas does happen frequently and reservoirs and gullies are full of water sometimes even in January (McKay, 1968). To eliminate as much as possible the effects of chinooks, the area north of Red Deer was selected for the study. The most northern part of Alberta was excluded from the analysis because of the different physiographic characteristics of the area and scarcity of data required for analysis. The area is dominated by a muskeg and forest environment. These physiographic characteristics do influence the snowmelt patterns. The effect of season and environment on snowmelt rates have been assessed in previous studies (McKay, 1967).

The variations in snowpack accumulation and thawing and freezing periods, are related to the variation in altitude. In this study, the entire basin was considered as a unit which may not be possible in areas which differ considerably in elevation and may require additional delineation of snowline and elevation bands. The Rocky Mountains area was excluded from the analysis due to these reasons.

The general physiography of the study area is flat to rolling with local relief features predominating. Local topographic variations are the result of glacial erosion and deposition and of more recent fluvial action. The magnitude of local relief tends to increase from the southeast towards the north and west.

2. Selection of Basins

The basin area refers to the gross topographic drainage area upstream from a given gauging site. The five river basins; Upper Paddle River, Blindman River, Whitemud Creek, Swan River and West Prairie River were selected for analysis using the following criteria.

1. There is practically nil flow in the stream during the winter months from November to February.

2. The streamflow is a natural flow with no man made storage or diversion works upstream from the hydrometric station.

3. The streamflow is not appreciably affected by natural lakes in the basin.

4. The daily discharge measurements are available for the active or discontinued hydrometric station located on the stream at the outlet of the basin.

5. The hydrometric and climatological stations in the basin must have a minimum of six years of daily discharge, precipitation, temperature and snowcover data.

The location of the five selected basins is also shown on Plate No. 1. The necessary information for selecting the basins was drawn from the Water Survey of Canada, "1973 Surface Water Data Reference Index" and the Department of Environment Meteorological Branch, "July 23, 1974 Climatological Station Data Catalogue - The Prairie Provinces".

The analysis was intended for the natural flow conditions which may be disturbed if the basin has major storage or diversion works. Out of the five basins selected for analysis, only in the Blindman River Basin, a lake (Gull Lake) is located within the basin boundary. Hydrologic investigations (Alberta Water Resources, 1968) indicate that the recorded hydrometric flow data is not affected by the outflows or groundwater recharge from the lake.

The drainage area of the basins considered in the analysis, varies from 142 square miles for the smallest, the Whitemud Creek basin to 742 square miles, the largest, the Swan River Basin.

The low winter flow criterion was intended to keep the groundwater contribution to the spring runoff to a minimum.

CHAPTER II

SNOWMELT RUNOFF PROCESS

System Concept

The snowmelt runoff process constitutes thermodynamic and hydrologic changes on or below the soil surface. The interrelated flow and storage variables affected by these changes are shown in Figure 1 and are expressed by the following relation.

Precipitation = Snowmelt Runoff + Interception
+ Infiltration + Surface Retention
+ Groundwater Recharge + Evapotranspiration
+ Sublimation.

In this expression, precipitation, runoff, evaporation and infiltration are flow variables. The storage variables are: interception, surface retention (also known as depression storage), and groundwater recharge.

The preceding summer or fall precipitation in form of rain recharges the soil moisture and groundwater through infiltration into the soil. Depending upon the soil moisture conditions, the base flow in the soil subsurface contributes to the streamflow before freezing occurs in the upper horizons of the soil. The stored moisture stays in the frozen soil during winter and snowfall accumulates on the surface. A part of the precipitation is lost to evaporation or snow sublimation, interception and deep percolation. Thus the snowfall in the form of snowpack and the moisture in the frozen soil become intermittent storage.

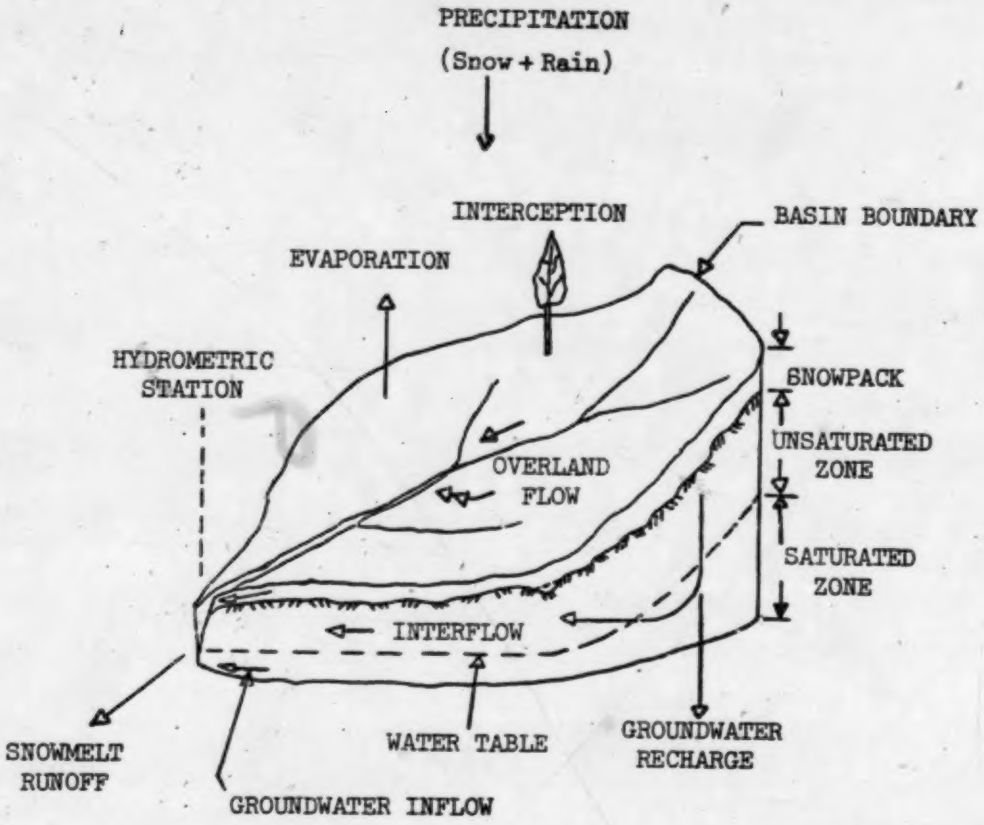

PRECIPITATION
(Snow + Rain)
INTERCEPTION
BASIN BOUNDARY
EVAPORATION
HYDROMETRIC STATION
SNOWPACK
UNSATURATED ZONE
OVERLAND FLOW
SATURATED ZONE
INTERFLOW
SNOWMELT RUNOFF
WATER TABLE
GROUNDWATER RECHARGE
GROUNDWATER INFLOW

FIGURE 1 - SNOWMELT RUNOFF PROCESS CONCEPT

With the onset of spring melting, aided by temperature, rain and wind, water begins to percolate into the snow and the frozen soil. The snowmelt runoff volume is a function of three variables;

Snowmelt Runoff = f (Snowfall Water Equivalent, Soil Moisture deficit, Rainfall during snowmelt and Groundwater Contribution)

The rate of percolation of the snowmelt runoff into the frozen soil depends largely on the soil moisture content at the time of freezing before winter. When the soil moisture requirements beneath the snowpack are satisfied and the temporary depression storage is full, the snowmelt runoff appears in the streams. Thus the snowmelt runoff contributes to the streamflow through both, the overland flow and the subsurface flow. Temporary depressional storage may also contribute later.

The overland or surface flow is the flow which travels over the ground surface including that through the snowpack and the channel towards the basin outlet. The subsurface flow is the total of the snowmelt runoff travelling to the stream through the subsurface.

Description of Mechanism

1. Formation of Snowpack

The fresh fallen snow is subjected to climatic elements such as wind, heat exchange resulting from convection, condensation and radiation, the pressure of the overlying snow, temperature variations, melt water and ground heat. The result of structural and density changes causedbby these elements is a snowpack, a porous medium composed of ice crystals of various shapes, through which a water or air-water mixture can move, For the determination of the snowmelt yield and potential for high flow rates, water stored in the snowpack as well as its distribution on the area of the watershed is of importance. Water equivalent is the depth of water which would result from the melting of the snow.

The fresh fallen snow densities have been found to vary from 0.004 to .34 depending on the location and time of the year (McKay, 1967). The snowpack densities vary widely with the presence and loss of melt water. Studies for Regina and Southern Manitoba (McKay and Thompson 1967) indicate value of 0.2 in January to about 0.35 at the time of melt. With the presence of liquid water in alternating freeze-thaw cycles in the melt season, density rises to as high as 0.5 and drops when the water drains away (U.S. Corps of Engineers, 1956).

On the Prairies, the general snowpack depth is fairly uniform. However, local variations in topography and vegetative cover influence snow accumulation and departures from this general statement are possible. Information on the dates of formation, loss, duration and depths of snowpack, is available for the Prairie conditions (McKay and Thompson, 1967).

2. Evaporation and Interception in Winter

Evaporation from snow occurs only when there is a vapour pressure gradient in the direction from snow to air. Where vapour pressure gradient is favourable, evaporation requires about 675-680 cal/gm to sublimate snow where as the heat of fusion is approximately 80 cal/gm. Investigations undertaken in the past (Diamond, 1953; West, 1959; Hutchinson, 1966; Gray, 1968; Maykut, 1969) indicate that the energy surplus in cold climates during winter is small and the air temperatures being low, evaporation losses are generally accepted as negligible, Even in the very favourable climatic conditions of the California Sierra,Nevada (West, 1962) assessed losses are less than 3%. Unless there is warm dry wind, chinook blowing over the snow, evaporation from snow is negligible.

Interception of snow by forest canopy is dependent on factors such as snow characteristics, wind movement and the geometry of the forest biomass. Interception losses from the forest canopy do occur through evaporation and sublimation from the snow surface on the trees. However,interception is small in comparison to the other terms in the water balance equation and does not influence the snowmelt runoff prediction. Although tests carried out in Sierra, Nevada, California (Miller, 1962) indicate high interception losses, studies for northerly Canadian conditions (Miller, 1965) indicate that interception can be neglected.

3. Subsurface Flow Components

In the upper unsaturated layer of the soil, water does not fill the soil pores completely and these are partly filled with air or water vapour. Water movement in this unsaturated zone takes place through the combined action of gravitational and capillary forces. The rainfall recharge of the soil moisture storage before freeze-up is rapid and limited only by the availability of water at the surface and infiltration capacity of the soil. After the recharge, the soil moisture is depleted by evapotranspiration, deep percolation to groundwater and lateral movement in response to a potential gradient. The flow which travels laterally downslope due to the potential gradient below the surface and emerges in the channel, is the base flow and consists of two components, the interflow and the groundwater inflow.

a) Interflow

Freezing of moisture in the soil layers results in formation of ice crystals. The infiltration rate of the frozen soil is governed by the quantity and size of the ice free pores which makes the moisture content of the soil at the time of freezing an important factor. Rapid changes take place at the time of moisture recharge by snowmelt. As the wetting front advances through the soil the pressures due to gravity and capillary forces change, resulting in changes in infiltration rate of the soil. Depending upon the intensity of the snowmelt rate relative to the infiltration rate, water may flow to the stream as interflow or may accumulate under the snowpack as a saturated layer and move downslope through the snow (Dunne and Black, 1971).

b) Groundwater Inflow

The groundwater contribution has an important role in the snowmelt runoff generation (Dincer, 1970, Stephenson and Freeze, 1974). The snowmelt water infiltrates into the soil and induces a widespread water table rise. The potential gradient in the basin increases and, in turn, the groundwater discharges into the stream. Baseflow component of the stream hydrograph generally indicates an increase in the spring and this increase is due to the groundwater discharge into the stream. Martinec (1975) concludes that the infiltrated water displaces previously stored water in the subsurface and the displaced water appears in the stream.

4. Surface Flow Components

a) Snowmelt Initiation

The snowmelt is a thermodynamic process, involving ripening of snow and subsequent release of stored moisture from the snowpack. The main phenomena responsible for generation of snowmelt is the heat exchange between the snowpack and its environment. Sources of this heat exchange are:

1. The solar radiation
2. Conduction of heat from the ground air and warm rain
3. Latent heat of vaporization released by the condensation of water.

The shortwave solar radiation absorbed by the snowpack depends upon the solar altitude, cloudiness, humidity and ozone in the air and amount of dust in the air. All these factors affect the reflectivity of the shortwave radiation of a snowpack, commonly known as Albedo. Albedo values range from 80% for freshly fallen snow to 40% for late melt season snow. The longwave radiation is influenced by the temperature of the snow surface and air close to the ground, air humidity, cloudiness and wind velocity olose to the ground.

It has been observed on the Prairies (Gray, 1968) that in most winters the flow of heat within the ground underlying the snowpack is towards the soil surface and there is gradual lowering of the soil temperature. However, this observation is questionable because of the low thermal conductivities of soil and small thermal gradients, the net transfer of heat may not be of sufficient magnitude and rate to cause melting of the Prairie packs. Warm rain is relatively more influential in melting the pack. The condensation of water releases heat which is absorbed by the snowpack and results in its melting. The vapour pressure gradient and wind aid the condensation process.

In a study on the Prairie snowpacks (Gillies, 1968) it was observed that the percentage of the total water content of the overlying pack which infiltrated into a frozen soil is related to the initial soil moisture content of the 2 surface layer prior to melt. Another observation was that a lower moisture content, caused a faster advance of the wet front from snowmelt into the frozen soil. If the soil is wet and frozen, there will be more surface runoff.

b) Snowpack Depletion

The snowpack water percolates into the snowpack, further accelerating the melt metamorphism. As the process progresses, the large crystals break up and form small grains. Reduction in grain sizes causes a closer packing of the grains by gravitational settlement and increases density of the snowpack. The melt is controlled not only by atmospheric conditions but also by the conditions of the snowpack and its environment.

The snowpack characteristics affect the volume as well as the time distribution of the snowmelt runoff. Rainfall and melt water may both be stored in substantial amounts within the snowpack and the pack may exhibit the ability to detain these for periods as much as two days (U.S. Army Corps of Engineers, 1956). The time distribution of snowmelt runoff flows appearing at the outlet of the basin, is also a function of the physical characteristics of a drainage basin and is reflected in the shape of runoff hydrograph for that basin. The potential of snowmelt increases rapidly as the spring advances and the air temperature rise accelerates the heat exchange process.

c) Rainfall in the Snowmelt Season

As the temperatures rise above 32°F, the warm rains accompanied by moderate winds result in rapid snowmelt. Rain breaks down the snowpack structure and speeds up the release of stored water. The rapid runoff may also wash unmelted snow into the stream. However, the volume of snow actually melted by the heat of rainwater may be small.

Before an appreciable amount of snowmelt runoff may occur, the rainfall amount should be sufficient enough to affect the snowpack characteristics and meet the soil moisture and depressional storage requirements.

CHAPTER III

AVAILABLE DATA AND RECORDING TECHNIQUES

Data Requirements

The hydrologic analysis is primarily based on the recorded data in the selected basins. Three types of data; hydrometeorological, surface water and soil data, are important for the analysis. The hydrometeorological observations consisting of precipitation, temperature, wind velocity, humidity, radiation and evaporation, are recorded at the climatological stations. Flow measurements are obtained from the daily discharge records of the gauging stations located on the streams. Soil data includes detailed information on the soil classification and soil moisture measurements over the basin.

The climatological stations provide complete information at the principal stations located close to the urban areas, particularly at major airports and experimental and other research stations. At other stations, complete information on all meteorological parameters is available only for short periods. Moreover, the principal stations are few and are located away from the boundary of the selected basins. The daily discharges are well recorded. The soil data is most difficult to obtain and soil moisture measurements representative of large watershed areas, are unavailable. Thus to make best use of the available information, analysis procedures were modified and the recorded data on the following parameters were obtained for analysis;

1) Mean monthly rainfall for summer months,

2) Mean daily snowfall and rainfall for the winter season,
3) Mean daily temperatures in fall, winter and spring,
4) Precipitation and temperature summaries indicating snowcover and temperature variations on a monthly basis,
5) Daily discharge records for the gauging stations located at the basin outlets.

Data Sources and Measurement

1. Hydrometeorological Observations

The Meteorological Branch of the Atmospheric Environment Service, Environment Canada, maintains records of all first-order climatological stations in Alberta. Most of the parameters are measured on 24 hour basis.

In addition to the Meteorological Branch stations, ordinary climatological stations are operated by; the Canada Department of Agriculture, Alberta Environment, Alberta Forest Service and Federal and Provincial Research Councils. The stations operated by the Alberta Forest Service are located at various lookout towers and ranger stations. Alberta Environment also maintains short duration stations in selected watersheds for research and provincial studies.

The location of first-order and ordinary climatological stations in Alberta is shown on Plate No. 2. It is important that a high degree of accuracy is maintained in the observations. The various techniques by which the data used in the study has been recorded, are as follows.

1) Precipitation

Precipitation is measured in the form of rainfall and the water equivalent of snow. The unit of measurement is the inch. A day with measurable rain is one on which 1/100th of an inch or more rain has fallen and a day with snow is one with at least one tenth of an inch of newly fallen snow. Any amounts less than this are registered as traces.

Rainfall is measured with a standard rain gauge which is cylindrical in shape and has a collector, a funnel and a receiver. The diameter of the orifice is 3.57 inches and the orifice is kept at one foot above the ground. At some stations, recording rain gauges of tipping bucket type are also used for recording precipitation as a function of time, thus begining and ending of precipitation and the precipitation rates are known. Each time the bucket tips it closes a switch momentarily which in turn operates an eletromechanical recorder. In some cases the output is directly recorded on a magnetic tape for processing.

Snowfall is taken as the depth of freshly fallen snow and is measured with a ruler in an area free from drifting. The Meteorological Branch and Agriculture Canada stations are equiped with Nipher snow gauges which measure the water equivalent of snow directly. The snow gauge consists of hollow metal cylinder 5 inch in diameter and is attached with a Nipher shield. The snow is melted and measured to obtain the water equivalent. Snow cover on the ground at the end of the month is also measured as the accumulation of snow on the ground on the morning of the last day of the month.

The precipitation observations are taken daily at fixed times of 0000, 0600, 1200 and 1800 Greenwich Mean Time with some stations taking one to three observations. The climatological day begins on the 0600 Greenwich Mean Time observation and ends on the next day 1600 Greenwich Mean Time observation.

2) Temperature

At most observation stations temperature is measured with liquid in glass thermometers. Mercury in glass thermometer is used for measurement of current and maximum temperatures and alcohol in glass for minimum temperatures. A standard louvred screen is provided to protect temperature readings from the effects of radiation. All observations are at a height of about 4 feet above the ground. In this study degrees Fahrenheit is used as the unit of measurement.

At principal stations both maximum and minimum refer to a 24 hour period beginning at 0600 Greenwich Mean Time. At ordinary climatological stations, the maximum temperature for a given day is the highest temperature in the 24 hour period beginning at the morning observation on the day while the minimum temperature is the lowest temperature recorded in the 24 hour period beginning at the evening observation, usually about 6:00 pm local standard time of the day. The mean temperature for the month is the average of the mean daily maximum and mean daily minimum tempratures.

2. Surface Water Data

In Alberta, the stream gauging station networks are operated by the Water Survey of Canada under the Water Resources Branch of the Federal Department of the Environment. In addition to this formal network, the Alberta Environment operates a limited number of stations for periodic gauge readings or for relatively short term records. The locations of the gauging stations are shown on Plate No. 3. Unit for discharge measurements is cubic feet per second. Discharge measurements are obtained by two methods. The Stage-Discharge Relationship developed at the gauging station is used to convert the recorded stage or water level to a corresponding discharge. Secondly, area of cross-section at the gauge is measured by soundings and using the velocity measurements, discharge values are obtained.

1) Stage Measurements

Manual as well as recording gauges are used. A manual gauge is a non-recording type of gauge from which observations of stage normally are obtained once daily. Water level is measured by a graduated marker in Manual Staff Gauge measurements. In another method, wire-weight type gauge is used to lower a weight to the water surface for water level reading. A recording gauge is a water-stage recorder from which continuous water levels are obtained on an analog chart. A digital recorder is used on the international gauging stations.

2) Discharge Measurements from Velocity and Area

Instrumentation techniques for these measurements are quite varied. For velocity, the Cup-type current meter is the general standard meter used on various streams. The Propeller-type has only specialized application. These meters measure velocity at a point in the cross-section of the stream. The number of revolutions are transmitted by a simple electric circuit and using the revolutions and time, velocity is obtained from a rating table.

The cross-sectional area is determined from the soundings. Various methods using sounding rods, sounding lines and weights and echo sounders are applied to compute the area.

Discharge measurements are also obtained from weirs, flumes and existing hydraulic structures.

Data Reliability and Limitations

The common errors in the precipitation data recorded by the gauges are related to the effect of the wind, instrumental errors and the evaporation loss. For individual readings, these errors may be small but when accumulative values are used, an inaccuracy in total values is possible since most errors are consistent. These types of accumulative errors affect the results when daily precipitation readings are used to compute the seasonal values of precipitation.

The instrumental error is loss by wetting of the receiver when transferring the precipitation to the measuring cylinder. Geographical and meteorological location of the station has a bearing on the evaporation losses. Wind effects on rainfall depend on the size of falling raindrops, the wind velocity and receiver shape. In the case of snowfall measurements, blowing out of catch may cause negative errors. The Canadian Nipher Shield can cause a significant increase in the catch because of raindrops splashing off the screen. Capping over of the screen can also occur in the snowfall season.

The number of climatological stations in the selected basins varies. Although dense networks give a more reliable value of the areal average of the measured parameter, in this study it was assumed that the precipitation characteristics are similar even if there is difference in the gauge network density. In computations, there were few instances when precipitation or temperature values were missing for the stations within the selected basins. Recorded values for stations outside the selected basins but close to the basin boundaries were used in such instances.

The reliability of the surface water data depends upon the stability of the stage-discharge relationships, the accuracy of the observations of stage, measurement of discharge from area and velocity and interpretation of results. Where manual gauges are used water levels sometimes fluctuate due to surge and wave action. Other operation problems are condensation, freezing of components, thickness of lubricants, freezing of ink and operation difficulties with electrical equipment. Water Survey of Canada publications for surface water data do indicate partially the reliability of the records and symbols for inaccuracies or estimates are given in the publications. In general, the water level data collected by water-stage recorders are more reliable and accurate than manual readings.

CHAPTER IV

ANALYSIS FOR DETERMINATION OF VARIABLES

General

The recorded data for the selected basins was analized to determine the snowmelt runoff variables and the volume of snowmelt runoff in spring. The three main variables are;

1. Accumulated Snowfall Water Equivalent
2. Antecedent Moisture Conditions of the Soil
3. Rainfall during the snowmelt period.

To find proper indices representative of the basin conditions, various approaches as discussed in this section have been applied. As an aid to understand the application of these procedures, the Paddle River Basin example is duscussed as an example. Detailed calculations for this basin are presented in Appendices A, B, and C.

Accumulated Snowfall Water Equivalent

The Water equivalent of snowfall in inches can be assumed as an index representing the accumulated snow in one season. The recorded values of precipitation in the form of "snow on the ground", is the gross amount of precipitation at the climatological station and includes evaporation or snow sublimation which may take place after the snow is on the ground. In winter, on the Prairies, the amounts of incident radiation received on relatively flat areas is small due to the low solar elevation (Williams, 1961; McKay, 1970). Although the total water equivalent figure includes evaporation loss, it is assumed negligible for the purpose of this study and the total recorded snowfall water equivalent is assumed to be the Snow-Index for the basin.

The amounts of rainfall recorded during the snowmelt period were separated from the snowfall on the basis of daily temperatures. The average values of Snowfall and rainfall over the basin, were computed by the Thiessen Polygon Method.

1. Separation of Snowfall and Rainfall Events

Freezing conditions were assumed to prevail over the basin when the mean daily temperatures approached 32°F in late fall and it was assumed that thawing initiated with the mean daily temperatures rising above 32°F. The mean daily temperature is the average of the maximum and minimum temperature for the day at one or more climatological stations located within the boundaries of the basin. The day with rain is thus the day on which precipitation occurred and the mean daily temprature was more than 32°F.

Data for various basins indicates that freezing initiation periods generally vary from 1st to 10th of November and thawing initiation periods vary from 20th of March to 10th of April. This is comparable to the mean dates of 15th of November and 10th of April for formation and disappearance of snowpack in Central Alberta as given by McKay (1968).

There were intermittent periods of below freezing temperatures even after the initiation of snowmelt. Some days when the temperatures were close to 31°F or 33°F, periods of mixed snow and rain also occurred. To separate the rainfall and snowfall events, the Meteorological Branch Monthly Precipitation Summaries were used as a guide. These summaries give the total number of days with snowfall and the total recorded snowfall in inches during the month.

The freezing and thawing periods and the separation of snowfall and rainfall events for the Paddle River Basin, are given in Table 1, Appendix A.

2. Average Snowfall or Rainfall Over the Basin

The mean values of snowfall water equivalent and rain were obtained by applying the Thiessen Polygon Method (Figure 2). Some of the other methods used are: Simple Arithmetic Mean, the Isoheytal Method, the Percentage-of-Mean Annual Method and the Abbreviated Isopercentual Method. The Thiessen Method adjusts for non-uniform distribution of gauges by weighting each observed value. The method assumes that the amount at any station can be applied halfway to the next station at any direction.

The drainage basin area for the basin, was taken as the latest published drainage area enclosed by the topographic divide of the basin such that direct surface runoff from precipitation will drain by gravity into the stream. The precipitation stations were located on 1,250,000 Scale National Topographic Series and connecting lines were drawn. A polygon around each station was formed by drawing the perpendicular bisectors of the connecting lines. For the Paddle River Basin Thiessen Polygons are shown on Plate 4. The value of the weighted precipitation for the station was obtained by multiplying the daily value at the station by the percentage of the basin area covered by the polygon. Then mean daily value of precipitation was obtained by adding the weighted values of the various stations for that day. A new polygon was formed each time a station is added or taken from the network depending

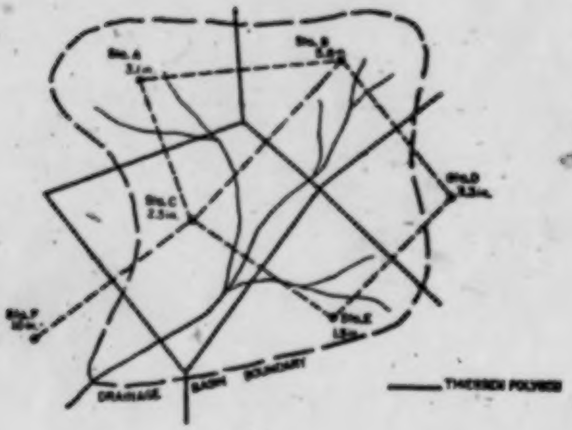


FIGURE 2 - THIESSEN POLYGON METHOD

upon the available data for various stations in the basin. The average values for the Paddle River Basin are given in Table 1, Appendix A.

The accumulative values of snowfall water equivalent and rainfall from freezing to thawing including the period up to complete recession of snowmelt were obtained from the average values over the basin in different months (Table 2). The date of snowmelt recession as marked in the hydrographic analysis is discussed later.

Soil Moisture Indices

In the field, soil moisture measurements for small experimental areas, are conducted through various methods such as Electrical, Chemical, Thermal, Gravimetric and Lysimeter Measurements. However, these approaches are impractical for large watersheds. In larger basins the soil saturation conditions can be expressed as indices in the form of groundwater flow or subsurface flow, antecedent precipitation and basin evaporation. The moisture content of the soil in summer and fall may also indicate the degree of saturation.

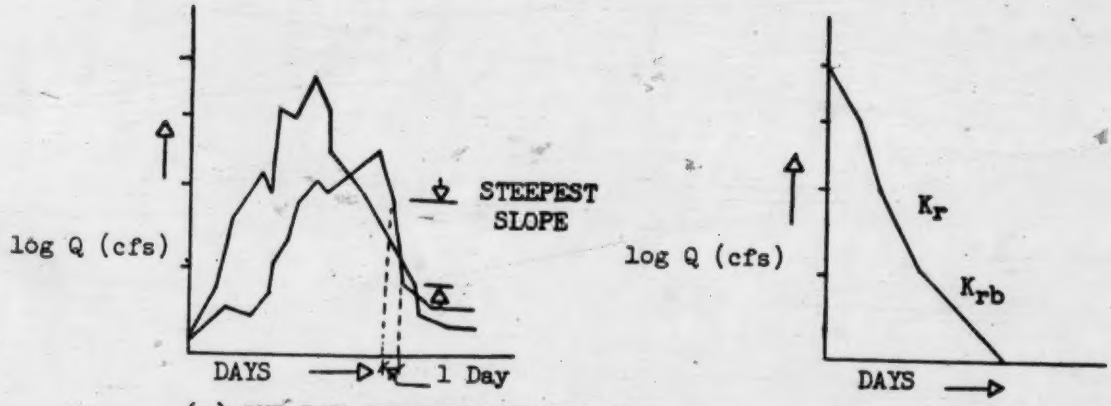
The various approaches applied in this study to assess the soil moisture conditions before freeze-up are;

1. Base Flow Storage as indicated by flow in the streams before winter,
2. Antecedent Precipitation Index (A.P.I.) reflecting the degree of wetness of the basin,
3. Basin Recharge Coefficient before freeze-up.

1. Base Flow Storage

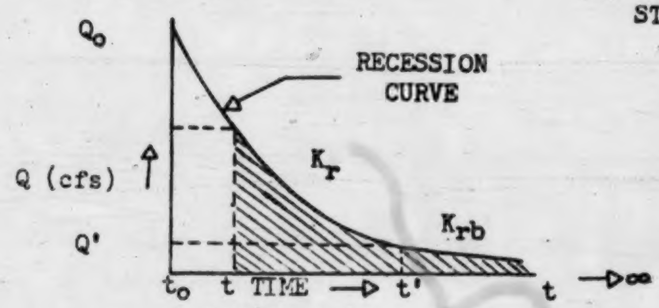
Depending upon the moisture content of the soil, the base flow contribution from the basin to the stream continues before freezing. The lower limb of the stream flow hydrograph in the recession period, represents withdrawal of water from the base flow storage and all other inflow to the stream generally ceases. However, in case of rainfall just before freezing some surface runoff may result. The discharge values plotted on a semi-logarithmic paper, with discharge on the log scale and time on the arithmetic scale show a straight line. The plotted discharge values between the hydrograph peak and the lower part of the recession limb show a curve on the same plot because of the combined effect of the surface and subsurface components of flow.

As shown in Figure 3, if the recorded summer hydrograph in various years are superimposed on each other and the steepest portion for each day is selected, the result would be a Base Flow Recession plot. The curvilinear relationship on a simple arithmetic scale will be the Base Flow Recession Curve.



(a) ONE DAY STEEPEST RECESSION

(b) COMBINATION OF DAILY STEEPEST RECESSIONS



(c) LINEAR PLOT

FIGURE 3 - BASE FLOW RECESSION CURVE

This recession curve for discharge Q at any time t, can be defined as:

$$Q = Q_o K^t \text{ ------------- } (1)$$

The value of the Recession Constant K decreases and is not constant as indicated by the semi-logarithmic plot in Figure b. Storage S_b at any time in the basin can be obtained by integrating Equation (1).

$$S_b = \int_t^{t'} Qdt + \int_{t'}^{\infty} Qdt$$

$$S_b = \left| \frac{Q_o K_r^t}{\ln K_r} \right|_t^{t'} + \left| \frac{Q' \; K_{rb}^t}{\ln K_{rb}} \right|_{t'}^{\infty}$$

Where Q_o = Discharge at the beginning of the computation period at time $t = 0$

Q' = Discharge at base flow recession time t'

$$S_b = \frac{Q_o}{\ln K_r}\left[K_r^{t'} - K_r^{t}\right] + \frac{-Q'}{\ln K_{rb}}$$

$$S_b = \frac{Q_o K_r^{t'} - Q_o K_r^{t}}{\ln K_r} + \frac{-Q'}{\ln K_{rb}} \qquad \text{-------(2)}$$

Where $Q_o K_r^{t'} = Q'$ and $Q_o K_r^{t} = Q$

Substituting in Equation (2)

$$S_b = \frac{Q' - Q}{\ln K_r} - \frac{Q'}{\ln K_{rb}} \qquad \text{-------------------(3)}$$

The recession constants K_r and K_{rb} were obtained by taking two discharges on the recession curve i.e., K_r from the upper segment and K_{rb} from the lower segment. The point of division between the two segments is the point where the slope of the straight line on the semi-lograthimic scale changes as shown in Figure No. 3-b. For example in the Paddle River basin case, using the base flow recession curve shown on Plate No. 5, values of K_r and K_{rb} are:

Q_o = 120 cfs
Q' = 4.7 cfs
t = 3 days

Q' = 4.7 cfs
Q'' = 1.2 cfs
t = 1 day

$$K_r^t = \frac{Q'}{Q_o} \qquad K_{rb}^t = \frac{Q''}{Q'}$$

$$K_r^3 = \frac{4.7}{120} \qquad K_{rb}^1 = \frac{1.2}{4.7}$$

$$K_r = 0.340 \qquad K_{rb} = 0.255$$

Using these Recession Constants, values of Base Flow Storage in Inches over the basin area, as calculated for the Paddle River Basin are given in Table 3, Appendix B. Storage for other selected basins were obtained by using the same procedure.

2. Antecedent Precipitation Index (API)

API was used as an index of the soil moisture deficiency. The soil saturation conditions were assumed to be related to the antecedent precipitation conditions over the summer and API at the end of October was obtained from the relationship;

$$API_{(o)} = a\,P_o + b\,P_s + c\,P_a + d\,P_j + e\,P_{ju} + f\,P_m$$

Where P_m, P_{ju}, P_j, P_a, P_s and P_o are the total recorded monthly rainfall for the summer from May to October. The monthly constants were assumed in such a way that the total of $a + b + c + d + e + f < 1$. Maximum weight was given to the month of October with the following decreasing scale, the minimum coefficient was used for the month of May.

a (October)	= 0.5	d (July)	= 0.0625
b (September)	= 0.25	e (June)	= 0.0312
c (August)	= 0.125	f (May)	= 0.0156

In the month of November for daily API values, the 31st of Oct. API value was taken as the starting value and using the following relationship, the API value before freeze-up was obtained.

API for today = k x API for yesterday + Average Precipitation over the basin for the intervening day.

Selection of the value of k is not critical. The U.S. weather Bureau River Forest Centres use an average value of $k = 0.90$ (Chow, 1964) and the same was assumed in this study. The average monthly and daily precipitation values for the basin were computed by Thiessen Polygon Method. So by weighting the previous day API and carrying over the effects of rainfall, values of API before freeze-up were computed as given in Table 4, Appendix B.

3. Basin Recharge Coefficient

The runoff and recharge coefficients before freeze-up are also indicatiors of the soil moisture conditions. The high runoff coefficient indicates less recharge to the subsurface. It was assumed that difference between precipitation and runoff is the recharge to the basin.

The month of October was considered to represent the fall conditions. The fall Basin Recharge Coefficient (BRC) is expressed in terms of monthly precipitation minus monthly runoff as a percentage of the monthly precipitation.

$$\text{BRC} = \frac{P_o - R_o}{P_o} \times 100$$

Basin Recharge Coefficients for the Paddle River Basin are given in Table 5, Appendix B. High values of BRC indicate dry soil conditions.

A comparison of the values of the BRC, base flow storage and API show as BRC decreases, i.e., the soil moisture increases, the base flow storage and API both increase.

Snowmelt Runoff

Methods such as the Energy Budget Approach (Anderson, 1968; Fohn, 1973; Price and Dunne, 1976), Degree-Day Correlations (U.S. Army Corps of Engineers, 1960), Basin Indexes (Martin, 1960), and Recession Analysis (Garstka, 1958), have been used for snowmelt runoff determination. In Canada successful use of Temperature Indexes have been reported in various studies (Simmons, 1959; Bruce and Clark, 1966; Psysklywee, 1966 and McKay, 1964). The application of the Energy budget Approach requires information on various parameters such as solar radiation, conduction and convective transfer of air mass above the snowpack, conduction from the underlying soil and heat supply from rainfall. In addition to the information requirements, the process involves determination of the effects of topography on solar radiation, wind temperatures and variations in the thermal quality and distribution of snow over the basin.

The Degree-Day and Basin Index Methods are commonly used but results depend upon the melting constant or the degree-day factor assumed in the basin-melt equations. Establishment of the constant requires long hydrologic records.

The approach applied in this study is a combination of the Degree-Day and Hydrographic Recession Analysis methods. The temperature indices above or below 32^{o}F have been used in conjunction with the recorded daily flows and the rainfall during the snowmelt season.

Hydrographic Analysis

Snowmelt determination from hydrograph analysis along with the use of temperature indices has the merit that field data are used and quantitative results are obtained from the hydrograph shape which already includes the effect of basin characteristics on the volume of runoff. The procedure adopted in this study included the following:

1. Determination of the Snowmelt Runoff Period from temperature and rainfall considerations.
2. Identification of rainfall volumes as a result of rainfall during the snowmelt season.
3. Determination of the Snowmelt Recession Curve.
4. Measurement of Snowmelt Runoff Volumes.

1. Snowmelt Runoff Period

The daily discharge values for each basin in cfs/sq. mile were plotted on an arithmetic scale along with the temperature, rainfall and snowfall as shown in Figure 4. The snowmelt runoff initiates with the seasonal change. Both the temperature and the rate of snowmelt runoff indicate similar upward trend in the months of March and early April. Due to the flat topography of the prairie basins, snowmelt mostly occurs simultaneously over the watershed. After the peak, the recession takes place over the months of April and May. The effects of any rainfall and rise and fall in temperature are indicated by the daily peaks. When the flow conditions approach Base Flow, the temperature effects are less significant as most of the runoff has already occurred.

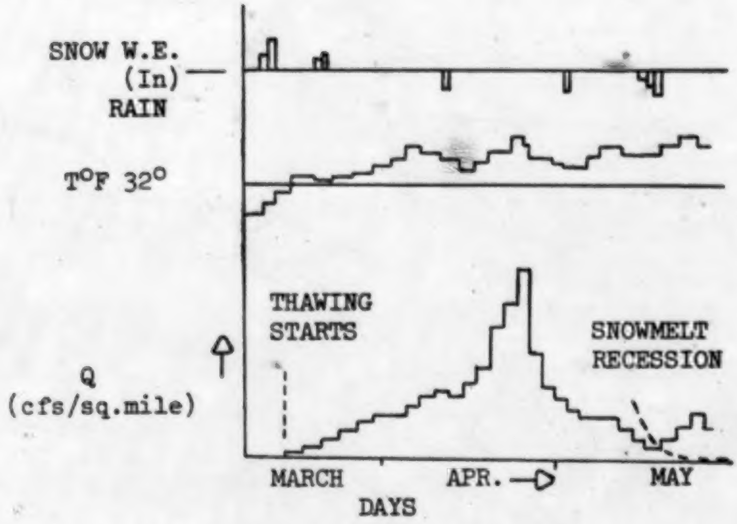


FIGURE 4 - TYPICAL SNOWMELT RUNOFF, TEMPERATURE, RAINFALL AND SNOWFALL PATTERN IN SPRING

Using the basin snowcover data as a guide which indicated the disappearance of snowpack and examining the individual rainfall events, the day close to which the snowmelt runoff recedes was identified on the hydrograph. On the basis of available hydrologic information on lag-times for these basins, a lag of one or two days was allowed after the rainfall event. For example, if a rainfall occurrence is indicated on the hydrograph (Figure 4) and it is clear that snowmelt has almost receded, recession time was assumed as one or two days depending upon the lag-time, after the rainfall event.

The flow hydrographs, snowmelt runoff periods and rainfall and temperature graphs for the Paddle River Basin are shown on Plates 6 to 16.

2. Rainfall Runoff Volumes

Rainfall during the snowmelt season accelerates the rate of flow and increases the volume of runoff. In this study, only the volume of runoff was examined. It was observed that on the rising limb of the flow hydrograph, generally in early April, the peak daily flows increase as a result of the combined effect of temperature increases and rainfall, if any. However, during the night freeze-up, the rainfall is absorbed in the snowpack and the effects are not clearly reflected on the hydrograph. In the falling limb there is better reflection on the increase in flows (Plates 6 to 16). The rises were mostly indicated one or two days after the rainfall event.

Two approaches were tried to separate the rainfall volumes on the hydrographs.

1) Assessment from variation of hydrograph slopes on the semi-logarithmic scale plots.
2) Rise or fall of daily flows indicated on the cfs/sq. mile hydrographs.

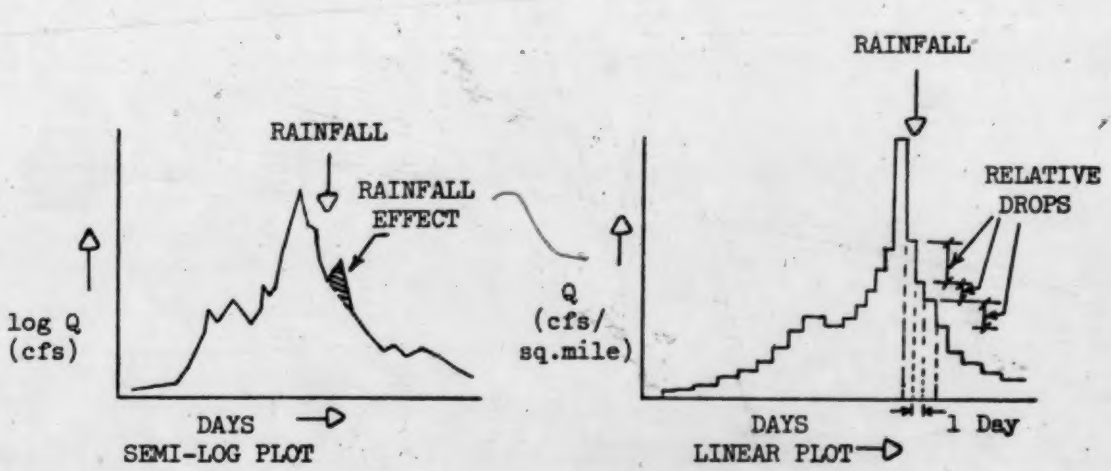

RAINFALL
RAINFALL EFFECT
log Q (cfs)
DAYS
SEMI-LOG PLOT
RAINFALL
RELATIVE DROPS
Q (cfs/ sq.mile)
DAYS
1 Day
LINEAR PLOT

FIGURE 5 - RAINFALL RUNOFF VOLUME DETERMINATION

a) Rainfall Runoff Volume from semi-log hydrograph

The recession limb of the snowmelt hydrograph plotted on a semilog paper follows a general slope which decreases with time. As shown in Figure 5, if there is rain, it is indicated by an abrupt change in slope. After the rainfall effect is over, the snowmelt recession continues at the same rate as before rainfall. This phenomena is more clearly indicated on Plate No. 17. The dotted line separates the rainfall volume and has been marked at a slope equal to the mean of the recession slopes ten days before and ten days after the rainfall event.

b) Rainfall Runoff Volume from cfs/sq. mile Graph

The rainfall event causes a rise in the rate of flow on the rising limb of the snowmelt hydrograph. The relative drops on the falling limb indicate the change in daily flows and in case of rainfall this drop decreases as shown in Figure 5. The rainfall effects on the drop in the daily flow rates are shown on Plates 6, 9 and 12. In some cases as shown on Plates 8, 10 and 15, the recession limb instead of a decrease in the relative drop, indicates a rise, same as reflected in the semi-log hydrograph. The changes in the daily flow rates due to rain were converted into volume of runoff in inches over the basin and are given in Table 6, Appendix C.

3. Snowmelt Recession Curve

When snowmelt recedes, the recession limb of the hydrograph may or may not decrease to zero discharge depending upon the magnitude of Base Flow. The decrease in the rate of discharge varies from basin to basin. Moreover, the snowmelt draining-off process may take more time than the summer runoff recession. The shape of the snowmelt recession curve depends upon the channel and basin characteristics. As discussed earlier for Base Flow Recession Curve, the Snowmelt Recession Curve also follows the relationship;

$$Q = Q_o K_r^t$$

Using a similar procedure, the daily discharges were plotted on the semi-logarithmic scale and superimposing the snowmelt hydrographs on each other, Steepest portions on a daily basis were determined. The snowmelt recession curve was obtained by combining the steepest portions. The semi-logarithmic curve was changed to an arithmetic scale with daily discharges plotted as cfs/sq. mile.

The snowmelt recession curve was used to calculate the snowmelt runoff after it was clear that the surface runoff from snowmelt had receded and flow in the stream was low, mostly the interflow. The runoff recession referred to as the snowmelt recession date in Figure 6 and Plates 6 to 16 was assumed on the following basis.

1) Using information on snow on ground at the end of the month as given in the Meteorological Branch precipitation summaries. If there was no snowcover at the end of the month, date was decided as one or two days after the major rainfall event in the basin depending upon the lag-time.

2) In the absence of the snowcover data, the base flow before freeze-up was used as a guide. The snowmelt recession date was assumed one or two days after the major rainfall event provided the stream flow was close to the base flow and the mean daily temperatures in the basin were above [illegible]

32°F for a period of at least ten days prior to the rainfall event.

The snowmelt recession dates for the Paddle River Basin are shown on Plates 6 to 16 and the snowmelt recession curve is shown on Plate No. 18.

4. Snowmelt Runoff Volume

Volume of snowmelt runoff were computed from the daily flow ordinates for the period from March to the identified snowmelt recession date. The ordinates for the area under the recession curves were obtained from the cfs/sq. mile plotted hydrographs. Any rainfall volumes in the snowmelt period were subtracted from the total gross volume of snowmelt hydrographs.

Typical computations for the Paddle River Basin are given in Table 6, Appendix C.

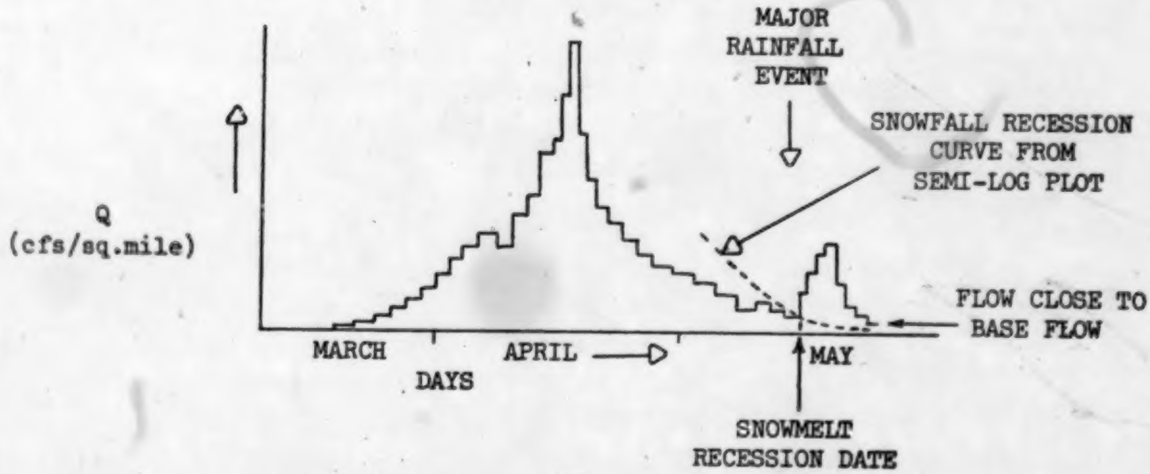


FIGURE 6 - SNOWMELT RECESSION CURVE

CHAPTER V

CORRELATION OF VARIABLES

Correlation Method

The results of analysis for the five selected basins are summarized in Table 7. The correlation of variables to each other was obtained by graphical means. A visual examination of the results, did not make it clear whether the variables would follow linear or differential relationships, so four different approaches were adopted for plots as shown in Figure 7. The following alternatives were tried by assuming the variables as dependent or independent.

1. Taking snowfall water equivalent, base flow storage, antecedent precipitation index and basin recharge coefficient as independent variables and snowmelt runoff as a dependent variable such that;
    1) Snowfall water equivalent and snowmelt runoff are represented on the horizontal and vertical axis (Figure 7 - a)
    2) Base flow storage, API or BRC on the horizontal axis and snowmelt runoff on the vertical axis (Figure 7 - b)
2. Taking total precipitation (snow and rain), base flow storage, API and BRC as independent variables and total runoff during the snowmelt period as a dependent variable such that;
    1) Precipitation and runoff are represented on the horizontal and vertical axis (Figure 7 - c)

2) Base flow storage, API or BRC on the horizontal axis and total runoff during the snowmelt period on the vertical axis (Figure 7 - d)

It was observed that inclusion of rainfall volumes made little difference in the plots. Also as presented in Table 7, the value of rainfall during the snowmelt period, is a small percentage (less than 6 per cent except few values) and the difference in total runoff and net snowmelt runoff is only 1 to 3%. Consequently, although rainfall accelrates the rate of flow, its effect on runoff volumes is not appreciable.

Plots with Base flow storage, API or BRC on the horizontal axis and snowmelt runoff on the vertical axis are shown in Figures 8a, 9a and 10a. Similarly, the plotted values taking snowfall water equivalent on the horizontal axis and snowmelt runoff on the vertical axis, are shown in Figures 8b, 9b and 10b. To differentiate between the different curves, points for each curve are marked by a dot, cross or a circle.

Due to varied nature of the results and the uncertaintly that the readings will show any linear correlation, no attempt was made to develop equations through regression analysis. The curves were fitted by eye and then with interpolation, curves for 4", 5", 6", 7" and 8" snowfall water equivalent values were drawn.

TABLE 7 - SUMMARY OF VARIABLES

YEAR	SOIL MOISTURE INDEX BEFORE WINTER			SNOW	RAIN	SNOWMELT RUN-OFF VOLUME			
	API	BASE FLOW STORAGE (Ins x 10-2)	BRC %	W.E. (Ins)	(Ins)	SNOW W.E. ONLY (Ins)	SNOW W.E.+ RAIN (Ins)	PER CENT OF SNOW W.E.+ RAIN	PER CENT OF SNOWFALL W.E.
1. **Blindman River Basin**									
1964	0.71	0.06	98	4.19	0.80	0.10	0.12	2.4	2.4
1965	1.74	0.55	63	6.75	0.24	2.91	2.94	42.1	43.1
1966	1.19	0.41	50	4.90	0.12	1.08	1.08	21.5	22.0
1967	1.27	0.32	96	3.41	0.01	0.45	0.45	13.1	13.2
1968	0.94	0.07	99	4.02	0.73	0.12	0.12	2.5	2.7
1969	1.62	0.27	96	3.43	0.08	1.03	1.03	29.3	29.7
1970	2.03	0.19	91	5.15	0.14	0.95	0.95	17.9	18.4
1971	1.39	0.08	97	5.97	0.06	1.71	1.71	28.4	28.1
1972	0.87	0.07	91	5.46	0.73	0.84	0.84	13.6	15.4
1973	1.51	0.20	94	3.74	0.33	0.43	0.43	10.6	10.7
1974	1.74	0.29	91	6.43	0.32	2.36	2.36	35.4	36.5
2. **Paddle River Basin**									
1964	0.82	0.01	99	3.86	0.65	0.32	0.41	9.1	8.3
1965	0.83	0.18	61	7.17	0.18	3.39	3.40	46.2	47.2
1966	1.13	0.17	-	5.56	0.76	1.97	2.01	31.8	35.4
1967	1.20	0.14	88	5.89	0.07	0.88	0.89	15.0	14.9
1968	0.61	0.01	99	5.49	0.14	0.52	0.53	9.4	9.5
1969	1.42	0.05	97	4.01	0.03	1.43	1.44	35.6	35.7
1970	1.84	0.23	84	4.59	0.11	1.07	1.08	22.9	23.3
1971	1.25	0.03	96	6.60	0.13	2.24	2.31	34.3	33.9
1972	1.53	0.16	77	5.74	0.28	1.57	1.61	26.7	27.3
1973	1.40	0.05	-	4.34	0.21	0.74	0.77	16.9	17.0
1974	2.05	0.35	86	8.11	0.48	4.68	4.76	55.4	57.7
3. **Swan River Basin**									
1967	1.76	0.72	91	8.04	0.48	3.26	3.32	38.9	40.5
1968	1.12	0.35	96	6.84	0.39	1.16	1.17	16.2	16.9
1969	1.78	0.89	77	4.67	0.68	1.27	1.29	24.1	27.2
1970	2.20	-	50	7.16	0.21	2.59	2.60	35.3	36.2
1971	2.41	0.44	79	6.18	0.06	3.00	3.00	48.1	48.5
1972	1.81	0.60	56	8.38	0.04	3.79	3.79	45.0	45.2
1973	1.88	0.51	61	3.66	0.85	1.73	1.83	40.6	47.3
1974	2.48	0.76	70	8.87	1.07	5.27	5.42	54.5	59.4

TABLE 7 - SUMMARY OF VARIABLES (Continued)

YEAR	SOIL MOISTURE INDEX BEFORE WINTER			SNOW	RAIN	SNOWMELT RUN-OFF VOLUME			
	API	BASE FLOW STORAGE (Ins x 10^{-2})	BRC %	W.E. (Ins)	(Ins)	SNOW W.E. ONLY (Ins)	SNOW W.E.+ RAIN (Ins)	PER CENT OF SNOW W.E. + RAIN	PER CENT OF SNOWFALL W.E.
4. Whitemud Creek Basin									
1970	0.92	0.0001	100	3.85	0.12	1.34	1.35	34.0	34.8
1971	1.64	0.0012	100	6.10	-	2.14	2.14	35.1	35.1
1972	1.56	0.0002	100	6.51	0.55	1.60	1.61	22.8	24.6
1973	1.28	0.0056	99	4.98	0.42	1.00	1.01	18.7	20.1
1974	1.97	0.0141	99	6.93	0.17	4.43	4.44	62.5	63.9
5. West Prairie River Basin									
1963	1.72	0.08	96	8.71	0.21	3.95	3.99	44.7	45.3
1964	1.80	0.08	98	6.94	0.48	1.44	1.51	20.3	20.7
1965	2.52	0.67	72	6.42	0.50	4.79	4.86	70.2	74.6
1966	1.39	0.38	52	6.64	0.08	2.16	2.18	32.4	32.5
1967	1.43	0.14	93	8.32	0.00	2.59	2.59	31.1	31.1
1968	1.28	0.01	99	7.01	0.18	0.55	0.56	7.8	7.8
1969	1.41	0.03	79	4.57	0.37	1.45	1.56	31.6	31.7
1970	1.86	0.76	87	8.02	0.22	2.96	2.97	36.0	36.9
1971	1.68	0.15	93	8.68	0.19	2.83	2.88	32.4	32.5
1972	1.17	0.05	88	7.96	0.16	2.21	2.20	27.1	27.7
1973	1.33	0.28	86	4.50	0.33	1.66	1.67	34.6	36.9
1974	1.80	0.80	83	8.75	0.25	5.45	5.52	61.3	62.2

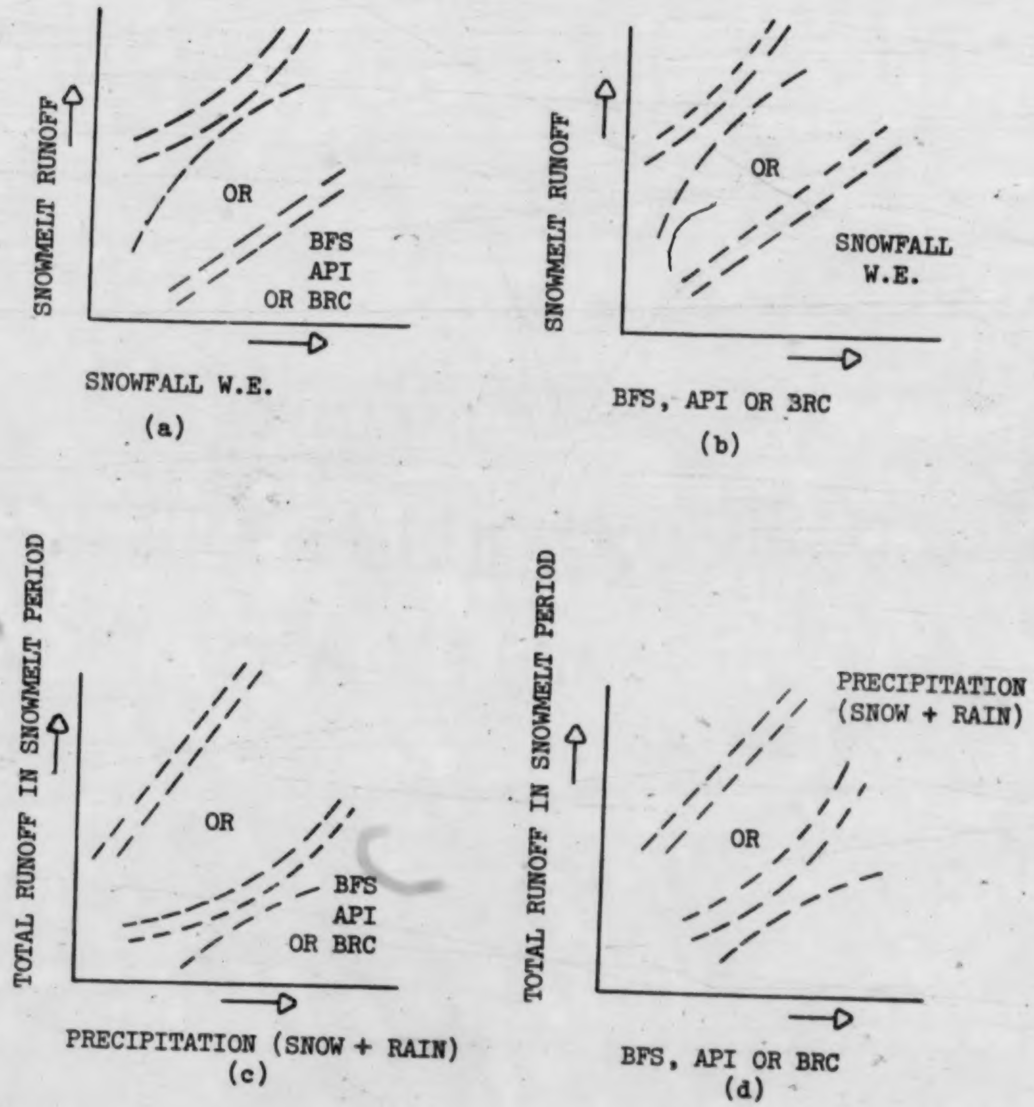
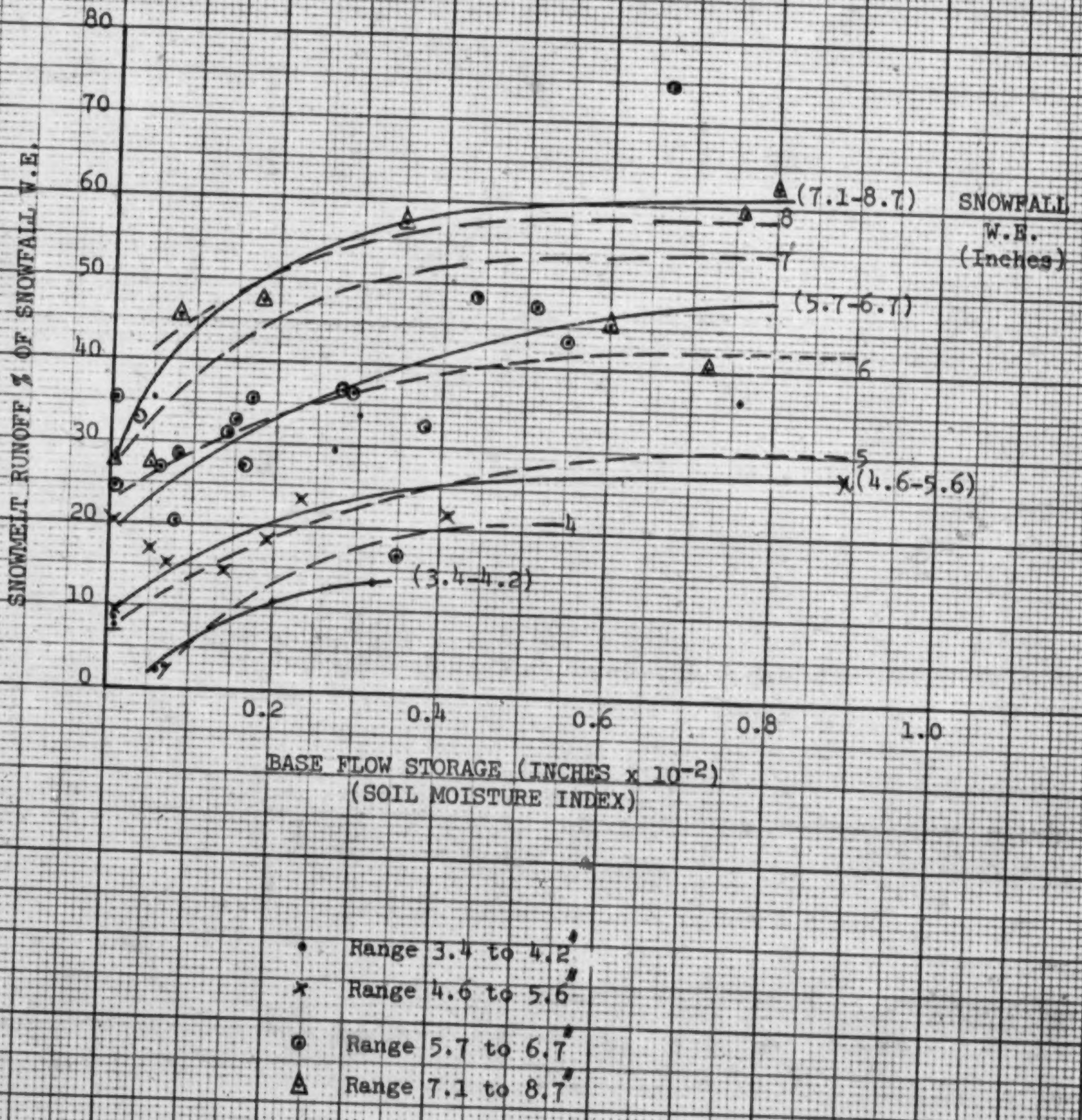


FIGURE 7 - APPROACHES FOR GRAPHICAL CORRELATION OF VARIABLES

FIGURE 8a

SNOWFALL W.E., BASE FLOW STORAGE AND SNOWMELT RUNOFF CORRELATION



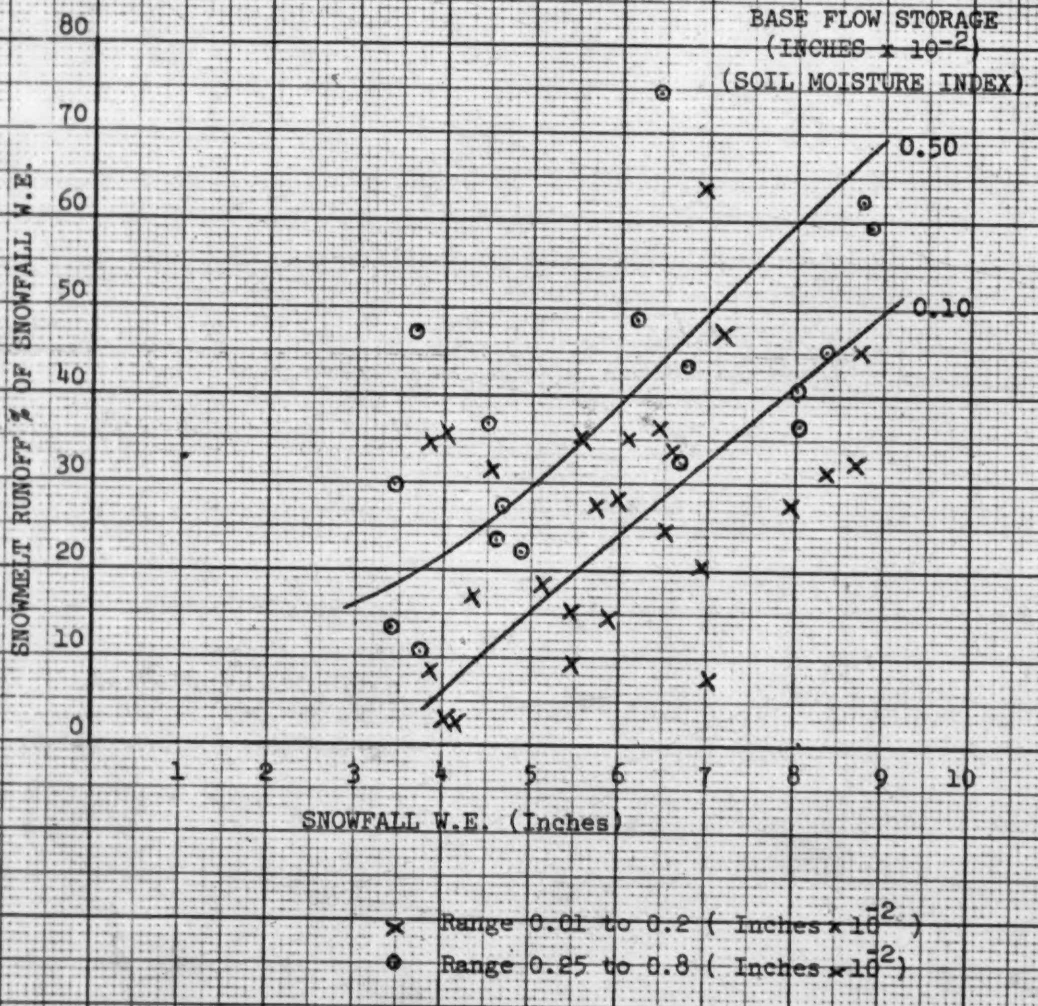
46 1240

K·E 20 X 20 TO THE INCH• 7 X 10 INCHES
KEUFFEL & ESSER CO. MADE IN U.S.A.

FIGURE 8b

SNOWFALL W.E., BASE FLOW STORAGE

AND SNOWMELT RUNOFF CORRELATION



K+E 20 X 20 TO THE INCH • 7 X 10 INCHES
KEUFFEL & ESSER CO. MADE IN U.S.A.
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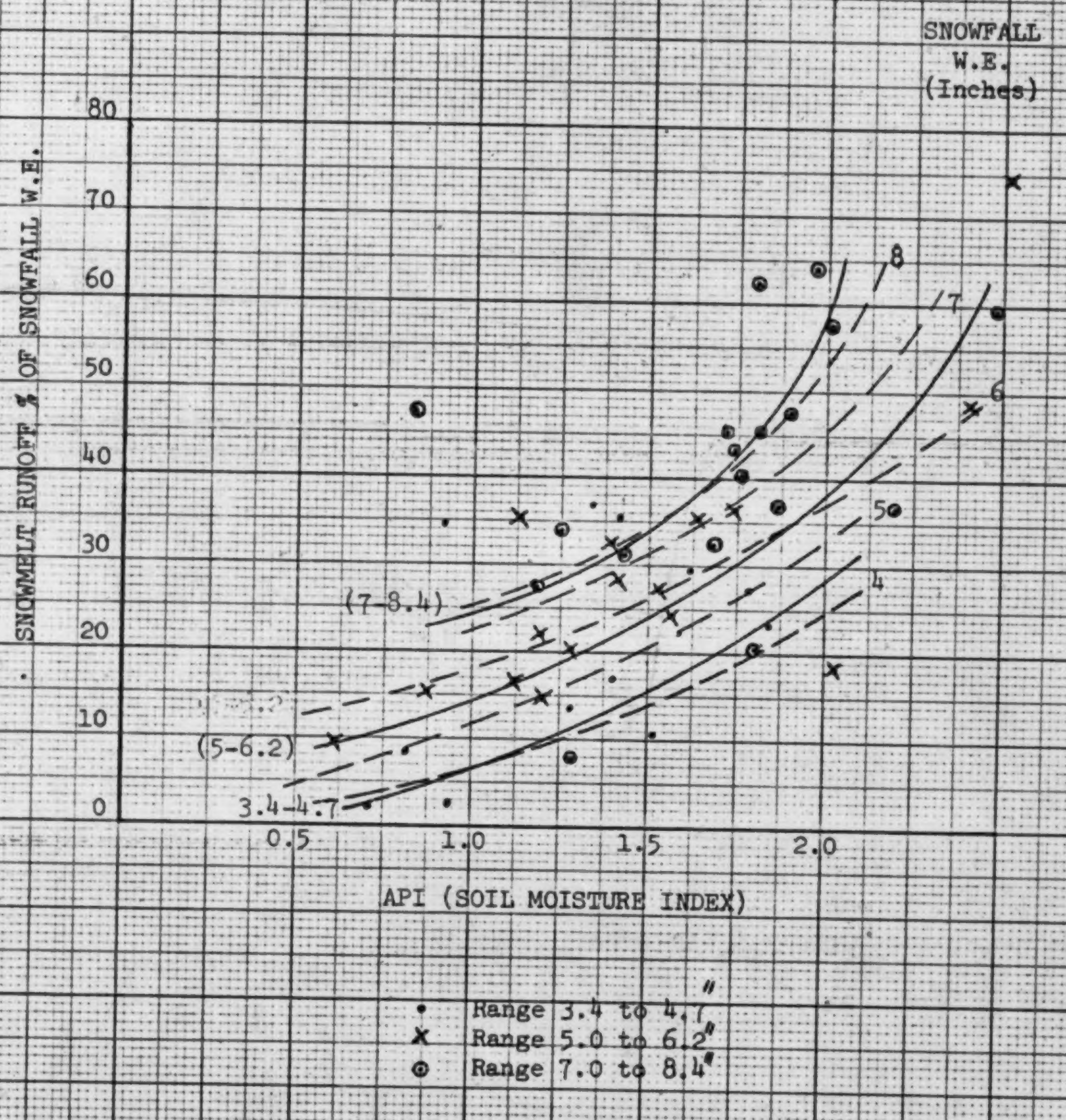
FIGURE 9a

SNOWFALL W.E., API AND SNOWMELT RUNOFF CORRELATION



46 1240
K&E 20 X 20 TO THE INCH • 7 X 10 INCHES
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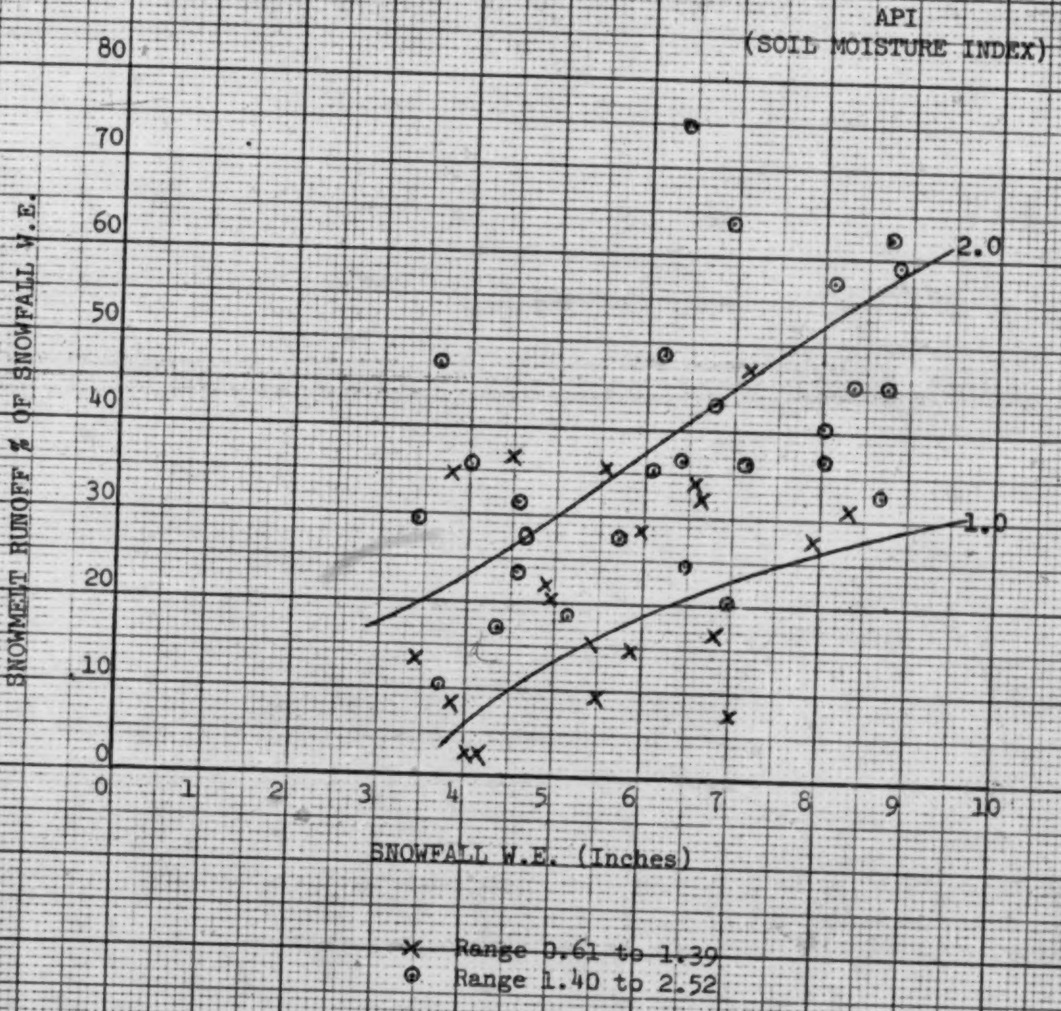
FIGURE 9b

SNOWFALL W.E., API AND SNOWMELT RUNOFF CORRELATION



K+E 20 X 20 TO THE INCH • 7 X 10 INCHES KEUFFEL & ESSER CO. MADE IN U.S.A.
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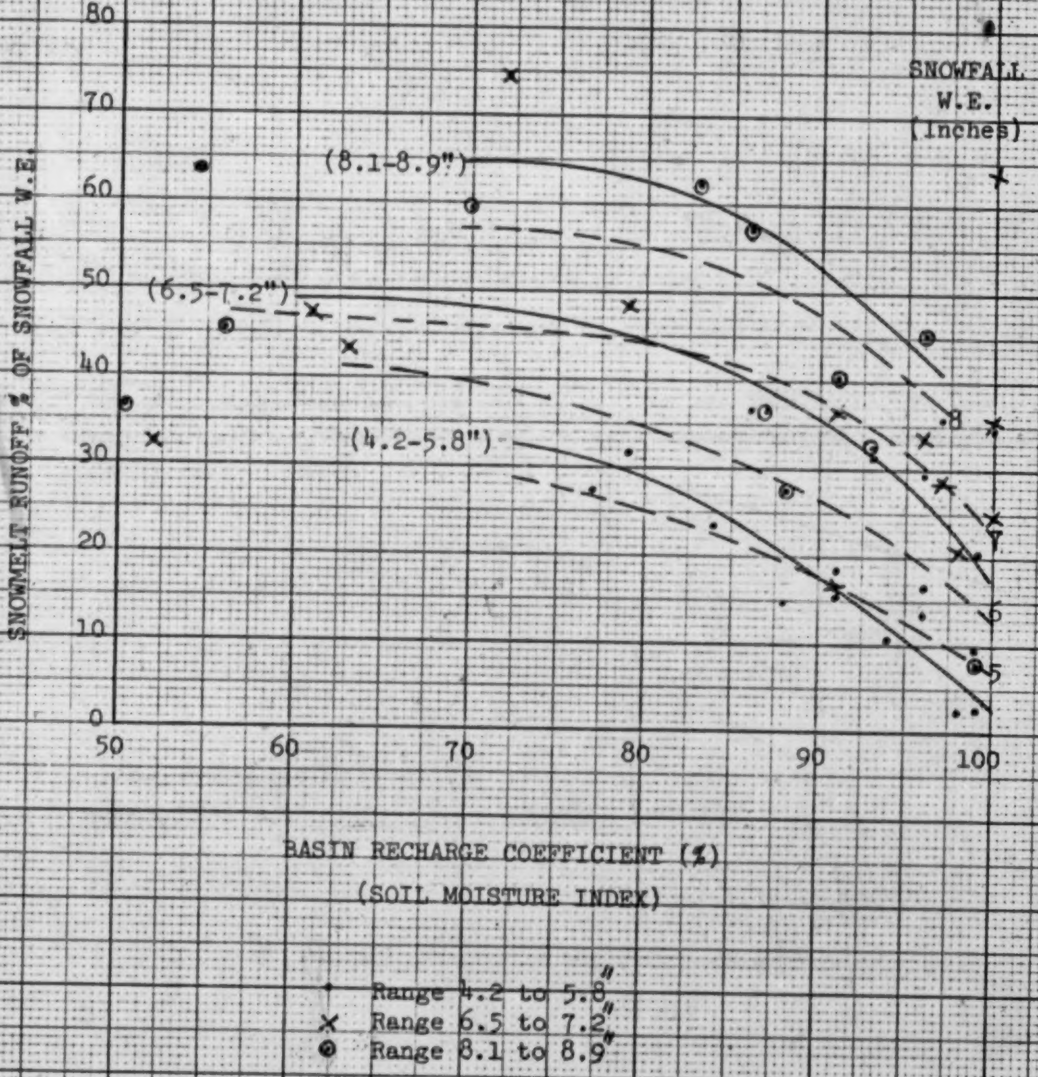
FIGURE 10a

SNOWFALL W.E., BRC AND SNOWMELT RUNOFF CORRELATION



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K·E 20 X 20 TO THE INCH • 7 X 10 INCHES KEUFFEL & ESSER CO. MADE IN U.S.A.

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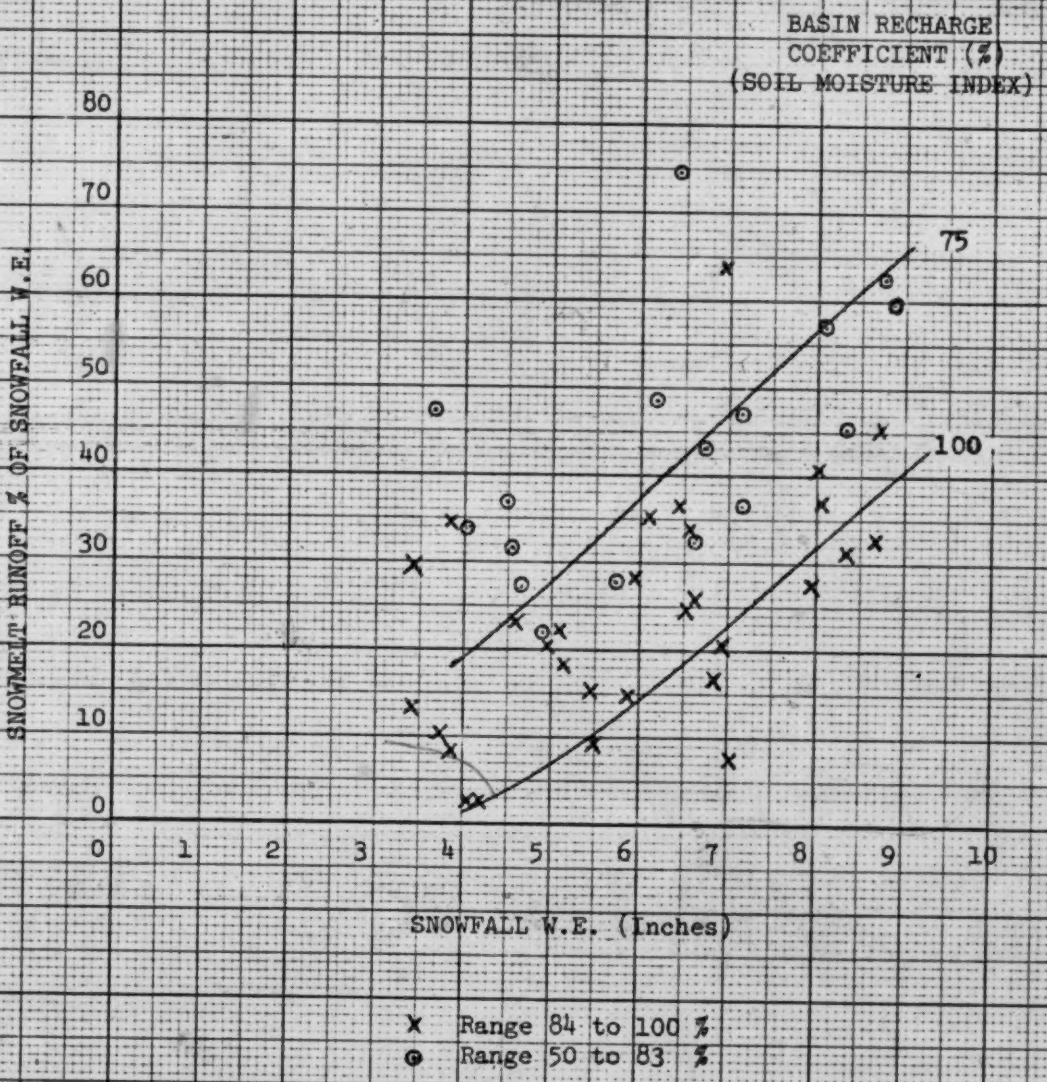
FIGURE 10b

SNOWFALL W.E., BRC AND SNOWMELT

RUNOFF CORRELATION



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Interpretation

Figures 8 and 9 for base flow and API indicate a definite correlation exists between the soil moisture conditions before freeze-up and snowmelt runoff depending upon the amount of snowfall water equivalent of the season. However, for the Basin Recharge Coefficinet (Figure 10) a definite pattern could not be obtained. Various reasons for this may be;

1. The assumed difference between the precipitation and runoff is not a valid definition of the BRC.
2. Other factors such as loss due to evaporation from the soil surface and evapotranspiration, may be predominating and the value of BRC may be dependent on the assessment of such losses.

Figures indicate that there are three ranges of values, the lower range for 3 to 4 inches of snowfall water equivalent, the middle for 5 to 6 inches and uppermost for 7 to 9 inches of snowfall water equivalent. The curves for 4", 5", 6", 7", and 8" have been drawn assuming a linear interpolation.

To check the interpolated curves and also to determine the nature of the correlation, snowmelt runoff values were obtained for the base flow storage, API and BRC values given in Table 7, using the curves in Figures 8a, 9a and 10a. The percentage error in comparison to the snowmelt volumes in Table 7, are given in Table 8. An examination of the values indicated the base flow storage and the API curves show better correlation in comparison to the BRC values. The base flow storage curves indicate minimum error and the BRC curves indicate maximum error.

TABLE 8 - SNOWMELT RUNOFF VOLUME

DETERMINATION FROM CURVES

YEAR	SNOWMELT RUNOFF % OF SNOWFALL W.E. AS OBTAINED FROM CURVES					
	BFS CURVES (FIG.8a)		API CURVES (FIG.9a)		BRC CURVES (FIG.10a)	
	VALUE	% ERROR	VALUE	% ERROR	VALUE	% ERROR
1. Blindman River Basin						
1964	2.4	0.0	3.0	25.0	4.0	66.0
1965	49.0	13.6	36.0	-16.4	45.0	4.4
1966	25.0	13.6	14.0	-36.4	33.0	50.0
1967	14.0	6.0	10.0	-24.2	9.0	-31.8
1968	2.7	0.0	5.0	85.2	2.7	0.0
1969	16.0	-46.1	14.0	-52.8	6.0	-79.8
1970	19.0	3.2	34.0	45.8	19.0	3.2
1971	28.0	- 0.3	24.0	-14.6	17.0	-39.5
1972	18.0	16.8	14.0	- 9.1	21.0	96.2
1973	11.0	2.8	10.7	0.0	10.0	- 6.5
1974	42.0	15.0	34.0	- 6.8	30.0	-17.8
2. Paddle River Basin						
1964	2.0	-75.9	4.0	-51.8	3.0	-63.8
1965	46.0	- 2.5	22.0	-53.4	50.0	5.9
1966	30.0	-15.2	18.0	-49.1	-	-
1967	25.0	67.7	20.0	34.2	27.0	81.2
1968	10.0	5.2	10.0	5.2	12.0	26.3
1969	2.0	-94.4	13.0	-63.6	7.0	-80.4
1970	22.0	- 5.5	25.0	7.3	20.0	-14.2
1971	30.0	-11.5	25.0	-26.2	27.0	-20.3
1972	27.0	- 1.1	25.0	- 8.4	34.0	24.5
1973	8.0	-52.9	15.0	-11.7	-	-
1974	57.7	0.0	56.0	- 2.9	55.0	- 4.7
3. Swan River Basin						
1967	58.0	43.2	43.0	6.1	46.0	13.6
1968	48.0	100.0	22.0	30.1	27.0	59.7
1969	27.2	0.0	24.0	-11.7	24.0	-11.7
1970	-	-	56.0	54.7	50.0	38.1
1971	44.0	- 9.2	50.0	3.1	38.0	-21.6
1972	60.0	32.7	46.0	1.7	62.0	37.2
1973	20.0	-57.7	20.0	-57.7	30.0	-36.5
1974	58.0	- 2.3	70.0	17.8	65.0	9.4

TABLE 8 - (Continued)

YEAR	SNOWMELT RUNOFF % OF SNOWFALL W.E. AS OBTAINED FROM CURVES					
	BFS CURVES (FIG.8a)		API CURVES (FIG.9a)		BRC CURVES (FIG.10a)	
	VALUE	% ERROR	VALUE	% ERROR	VALUE	% ERROR
4. Whitemud Creek Basin						
1970	2.0	-94.2	5.0	-85.6	3.0	-91.4
1971	25.0	-28.7	32.0	- 8.8	15.0	-57.2
1972	25.0	1.6	30.0	21.9	19.0	-22.7
1973	8.0	-60.2	16.0	-20.4	8.0	-60.2
1974	28.0	-56.2	45.0	-29.5	24.0	-62.4
5. West Prairie River						
1963	48.0	5.9	44.0	- 2.8	42.0	- 7.3
1964	32.0	54.5	38.0	83.5	25.0	20.7
1965	50.0	-32.9	57.0	-23.5	43.0	-42.3
1966	40.0	23.0	27.0	-16.9	45.0	38.4
1967	47.0	51.1	34.0	9.3	48.0	54.3
1968	23.0	100.0	27.0	100.0	26.0	100.0
1969	23.0	-27.4	17.0	-46.3	25.0	-21.1
1970	58.0	57.2	47.0	27.3	52.0	40.9
1971	49.0	50.7	42.0	29.2	48.0	47.6
1972	37.0	33.5	28.0	1.1	49.0	76.9
1973	23.0	-37.6	15.0	-59.3	20.0	-45.8
1974	62.2	0.0	62.2	0.0	60.0	- 3.5

In case of base flow storage and BRC (Figures 8 and 10), the curves become more or less horizontal reflecting that when the soil conditions approach saturation, volume of snowmelt runoff is more related to the amount of snowfall. However, the curves still indicate upward trend for API and the reason for this is not known.

The analysis also indicates that even if all basins were selected in the central region of Alberta, geographical variation and basin characteristics still reflect variation in results. The Whitemud Creek Basin results were in the lowermost range of values and the Swan River Basin results in the uppermost range and thus indicate relationship of the snowmelt runoff to the topography and location of the drainage basin. Both the Swan and the West Prairie River basins are close to 56° latitude in the upper area of the study region and the snowmelt recession dates are 10 to 15 days later in comparison to the other three basins.

There were one or two values in every basin which did not fit in the general trend indicated by the plots. A better correlation was obtained for those years where data was obtained from all stations within the basin boundaries than those in which data had to be transposed from stations outside the basin boundary.

Application

At present various tools being used for flood forecasting are; Precipitation - Runoff Relations, Unit Hydrographs, Routing Methods, Recession Curves and Stage-Discharge Relations. As the time factor is important in forecasting, consideration must be given to the development of forecast procedures through which necessary information for flood warnings can be obtained at the earliest possible time. The correlation developed here is a useful tool to aid in evaluation of such early forecasts. Before thawing conditions prevail, there is generally sufficient information on the snowcover in the basin. With the assessment of conditions before freezing, a fair estimate of the expected spring flood volume can be obtained. Moreover, rainfall events and recorded flood peaks can be related and with the flood volumes information, estimates of the flow rates are possible.

Most of the basins considered in this study are already subjected to detailed provincial studies in relation to flooding and water supply problems. The information presented here will also be useful for such assessments. For future water resource development in these basins, planning should take into consideration all the available means for assessment of the current situation and aim for better design of the water supply and flood forecasting systems.

CHAPTER VI

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

From this study, it is concluded that;

1. A definite correlation exists between the Soil Moisture conditions before winter, snowfall in winter and the volume of snowmelt runoff in the spring.
2. The two variables, Base Flow Storage and Antecedent Precipitation Index (API), are reasonable indices representing the soil moisture conditions in the basin. However, when Basin Recharge Coefficient is used as an index of soil moisture the results indicate poor correlation to the snowmelt runoff.
3. The correlation of the snowmelt runoff variables varies from one basin to another which reflects the influence of the basin characteristics even if the selected basins are located in the same geographic region.
4. The effect of rainfall on the total volume of runoff during the snowmelt period is not appreciable. However, rain does influence the timing of snowmelt and occurrence of snowmelt runoff.
5. The results are applicable only to areas comparable to the basins studied in this report. In comparable basins, the streamflows should be in natural state and should not be affected by any man made storage, diversion works or lakes in the basin.

Recommendations

The various aspects of the analysis and relationships developed in this study, need further research.

1. The flows in the streams and the snowmelt runoff patterns in the basins studied here, were not influenced by the man made reservoirs or diversions and natural lakes. Further research with larger basins with such influences, is needed for practical understanding of the problems being experienced in the basins such as the Vermillion River Basin, Sturgeon River Basin and the Lower Paddle River Basin. With the advancement in modelling techniques, possibly these basins can be considered in parts and the inflows and outflows from the existing lakes which retain a large volume of the snowmelt runoff, examined to provide a better understanding of the runoff process.
2. The theoretical assessment by the Energy Budget Approach and Degree-Day Correlation procedures, although limited due to the availability of data, can be tried and compared with the results obtained in this study.
3. Improvement in the rainfall runoff volume estimation methods and assessment of its appearance in the streams, is required. An underestimation of the volume will result in higher snowmelt runoff assessment for flood prediction, particularly in flood estimates made before the thawing season.
4. Further research is needed to evaluate the Basin Recharge Coefficient as a measure of the soil moisture conditions in the basin.

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APPENDIX -A

Table 1 -Average Precipitation, Freezing, Thawing and Snowmelt Recession Dates for Paddle River Basin

PERIOD	DESCRIPTION	THIESSEN POLYGON AREA	AREA %									DAY OF THE MONTH																							TOTAL P (In)	SNOW W.E. (In)	RAIN (In)
				1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31			
1963 Nov.	T (°F)			35	37	32	22	35	22	28	24	18	16	21	23	20	27	25	19	3	-7	-13	-22	-13	-14	-9	0	19	32	22	25	35	28				
	DAILY P (In.)																																				
	Peavine	93	36						.30										.21	.14	.12	.04						.05							0.86		
	Whitecourt	167	64						.17									.02	.20	.40	.17							.20	.04						1.20		
	WEIGHTED P																																				
	Peavine								0.11										.07	.05	.04	.01						.02							0.30		
	Whitecourt								0.11									.01	.13	.25	.11							.13	.02						0.76		
	Average P								0.22									.01	.20	.30	.15	.01						.15	.02						1.06	1.06	
	Remarks					Freezing																															
Dec.							Mean Daily Temperature for the Month								Recorded Precipitation									Weighted Precipitation													
	Peavine	93	36				14°F								.54									0.19													
	Whitecourt	167	64				10.8°F								.45									0.29													
																																			0.48	0.48	
1964 Jan.	Peavine	93	36				13.3								.58									0.21													
	Whitecourt	167	64				10.5								.43									0.27													
																																			0.48	0.48	
Feb.	Peavine	93	36				29.8								.53									0.19													
	Whitecourt	167	64				27.2								.88									0.56													
																																			0.75	0.75	
March	T (°F)			16	9	12	15	13.5	10	5.5	11	17.5	16	15	21.5	25.5	27	19.5	6	21.5	19.5	4.5	6	7	-6.5	-17	-11.5	-3.5	4	9.5	19.5	30.5	40.5	46			
	DAILY P (In.)																																				
	Peavine	93	36		.01	.04		.01			.10	.10						.10	.21				.09	.03											0.69		
	Whitecourt	167	64			.06	.04		.02		.14	.05	.04	.01				.03	.35				.09	.09	.01										0.93		
	WEIGHTED P																																				
	Peavine				.00	.01		.00			.04	.04						.04	.08				.03	.01											0.25		
	Whitecourt					.04	.03		.005		.09	.03	.03	.01				.02	.22				.06	.06	.005										0.60		
	AVERAGE P				.00	.05	.03	.00	.005		.13	.07	.03	.01				.06	.30				.09	.07	.005										0.85	0.85	
	Remarks																																Thawing				
April	T (°F)			43.5	43.5	38	41	29	34.5	38	44.5	43.5	47	39	38.5	41	44.5	36	29.5	27.5	39	46.5	37	38	37.5	35	42.5	44.5	42.5	39	40.5	51.5	47				
	DAILY P																																				
	Peavine	93	36				.97													.01								.36							1.45		
	Whitecourt	167	64				.44	.37					.02										.02					.01	.02						0.88		
	WEIGHTED P																																				
	Peavine						.35																					.13							0.48		
	Whitecourt						.28	.24					.01										.01						.01						0.55		
	Average P						.63	.24					.01										.01					.13	.01						1.03	0.24	0.79
	Remarks						R	S					R										F					R	R Snowmelt Recession								

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(Table 1 cont.)

PERIOD	DESCRIPTION	THIESSEN POLYGON AREA	AREA %	DAY OF THE MONTH																															TOTAL P (In)	SNOW W.E. (In.)	RAIN (In.)
				1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31			
1964 Nov.	T (°F)			44	28	27.5	35	35.5	41.5	34.5	26	15	26.5	29	30	21	10.5	29	33.5	23	24	28.5	16.5	27	16.5	17	9.5	-5	-2	-.5	-6	-16.5	-7				
	DAILY P (In.)																																				
	Peavine	93	36										.07	.44	.45	.02	.02									.30	.01	.04	.40	.09	.02	.37	.35		2.57		
	Whitecourt	167	64						.02				.02		.42	.07										.03	.17		.24	.18	.02	.05	.29		1.51		
	WEIGHTED P																																				
	Peavine												.03	.16	.16	.01	.01									.10	.01	.01	.14	.03	.01	.13	.12		0.92		
	Whitecourt								.01				.01		.27	.04										.02	.11		.15	.11	.01	.03	.19		0.96		
	AVERAGE P								.01				.04	.16	.43	.05	.01									.13	.12	.01	.29	.14	.02	.16	.31		1.88	1.88	
	Remarks										Freezing																										
Dec.							Mean Daily Temperature for the Month								Recorded Precipitation							Weighted Precipitation															
	Peavine	93	36				- 4.6								.88							0.32															
	Whitecourt	167	64				- 6.1								.38							0.24													0.56	0.56	
1965 Jan	Peavine	93	36				2.4								2.57							0.92															
	Whitecourt	167	64				1.6								2.21							1.41													2.33	2.33	
Feb	Peavine	93	36				7.8								1.92							0.69															
	Whitecourt	167	64				6.8								1.48							0.95													1.64	1.64	
Mar	Peavine	93	36				17.2								0.13							0.05															
	Whitecourt	167	64				16.5								0.18							0.11													0.16	0.16	
April	T (°F)			28.5	31.5	33	39	34	35	33	32	26.5	34.5	42	43.5	35.5	28.5	31.5	32	32	29	27.5	16	27.5	35.5	43.5	45	45.5	46	51	47	42.5	41				
	DAILY P (In.)																																				
	Peavine	93	36						.10	.02		.01				.16		.01	.01	.11	.05		.06								.04	.02			0.59		
	Whitecourt	167	64							.30				.04		.08	.06			.05	.21		.13												0.87		
	WEIGHTED P																																				
	Peavine						.04	.01						.06		0	0	.04	.02		.02								.014	.007			0.21		
	Whitecourt							.19				.03		.05	.04			.03	.13		.08												0.55		
	AVERAGE P						.04	.20				.03		.11	.04			.07	.15		.10								.01	.01			0.76	0.60	0.16
	Remarks						Thawing		S	S				R		R	S			S	S		S								R	R					
May	T(°F)			46	45	45	40	46	47	52	54	53.5	47.5	51.5	47.5	42.0	45.5	44	43.5																		
	DAILY P (In.)																																				
	Peavine	93	36														.06	.08	.02																		
	Whitecourt	167	64		.01											.03	.12	.34	.06																		
	WEIGHTED P																																				
	Peavine														.02	.32	.01																		
	Whitecourt				.01											.02	.07	.22	.04																		
	AVERAGE P				.01											.01	.09	.54	.05																		0.02
	Remarks				R											R	R		Snowmelt Recession																		
1965 Nov	T (°F)			39	31.5	20	21.5	20	19	19	22.5	22.5	22	12	13	10.5	16	12.5	14	16.5	21	15.5	20.5	20	16.5	5	-1.5	-6	-9	9	5.5	13	25.5				
	DAILY P (In.)																																				
	Peavine	93	36		.29		.03	.01				.06			.01						.20				.50		.08	.03	.01						1.22		
	Whitecourt	167	64	.02	.25		.07	.07				.04	.01								.01	.16			.22										0.85	0.85	
	WEIGHTED P																																				
	Peavine				.10		.01	.004				.02			.004						.07				.18		.03	.01	.004						0.43		
	Whitecourt			.01	.16		.04	.04				.03	.01								.01	.10			.14										0.54		
	AVERAGE P			.01	.26		.05	.044				.05	.01		.004						.08	.10			.32		.03	.01	.004						0.97	0.96	0.01
	Remarks											Freezing																									
Dec							Mean Daily Temperature for the Month								Recorded Precipitation							Weighted Precipitation															
	Peavine	93	36				10.1								.83							0.30															
	Whitecourt	167	64				7.5								.61							0.39													0.69	0.69	
1966 Jan	Peavine	93	36				-12.0								1.92							0.69															
	Whitecourt	167	64				-11.5								1.20							0.77													1.46	1.46	
Feb	Peavine	93	36				12.6								.96							0.34															
	Whitecourt	167	64				11.7								.76							0.48													0.82	0.82	

(Table 1 cont.)

PERIOD	DESCRIPTION	THIESSEN POLYGON AREA	AREA %	DAY OF THE MONTH																															TOTAL P (In)	SNOW W.E. (In)	RAIN (In)
				1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31			
Mar	T (°F)			9.5	.5	24	4	11.5	5	14	6.5	15	23	24.5	23	25.5	35	34	33	21.5	17	33.5	26	7	-1.5	14.5	27	33	42	46.5	46.5	47.5	43	48			
	DAILY P																																				
	Peavine	93	36								.02							.04	.25	.12															0.43		
	Whitecourt	167	64											.03				.01	.34	.27		.03					.02								0.70		
	WEIGHTED P																																				
	Peavine										.01							.01	.09	.04															0.15		
	Whitecourt													.02				.01	.22	.17		.02					.01								0.45		
	AVERAGE P										.01			.02				.02	.31	.21		.02					.01								0.60	0.60	
	Remarks																											Thawing									
April	T (°F)			37.5	41.5	39	42	48	41	35.5	30	31.5	13.5	16.5	21	26.5	38.5	40	33	24	22	26	36	37.5	46	48.5	39.5	39.5	33	20.5	20.5	23.5	35.5				
	DAILY P (In.)																																				
	Peavine	93	36	.14							.20	.49	.02		.01											.03	.17	.32	.07						1.48		
	Whitecourt	167	64	.04	.01							.60	.17	.04	.01								.03					.85	.23						1.98		
	WEIGHTED P																																				
	Peavine			.05							.07	.18	.01													.01	.06	.11	.03						0.53		
	Whitecourt			.02	.01							.38	.11	.02	.01								.02					.54	.15						1.26		
	AVERAGE P			.07	.01						.07	.56	.12	.02	.01								.02			.01	.06	.66	.18						1.79	1.03	0.76
	Remarks			S	R						S	S	S	S	S								R			R	R	R	S								
1966 May	T (°F)			43	49	56	57	55	62	57	54.5	60	57.5																								
	DAILY P (in.)																																				
	Peavine		100									1.05	0.19																								
	WEIGHTED P																																				
	Peavine											.38	.12																								
	AVERAGE P											.38	.12																								
	Remarks												Snowmelt Recession																								
Nov	T (°F)			25	37.5	31	21	20.5	4	5.5	6.5	19	10.5	10	5	-1	6	6	3.5	7.5	20	13.5	17	7.5	-5.5	17.5	27.5	33.5	31	10	-9	-6.5	-11.5				
	DAILY P																																				
	Peavine	93	36	.03				.04	.01		.02				.22		.22	.05		.02	.20			.20	.08			.09		.13					1.25		
	Whitecourt	167	64	.01			.05	.09		.02	.03	.14		.01	.21	.03	.10	.01	.04	.02	.21			.08				.15		.11	.11				1.42		
	WEIGHTED P																																				
	Peavine			.01				.01			.01				.08		.08	.02		.01	.07			.07	.01			.03		.05					0.45		
	Whitecourt			.01			.03	.06		.01	.02	.09		.01	.13	.02	.06	.01	.03	.01	.13			.05				.10		.07	.07				0.91		
	AVERAGE P			.02			.03	.07		.01	.03	.09		.01	.21	.02	.14	.03	.03	.02	.20			.12	.01			.13		.12	.07				1.36	1.36	
	Remarks																																				
							Mean Daily Temperature for the Month								Recorded Precipitation							Weighted Precipitation															
Dec	Peavine	93	36				12.8								.30							0.14															
	Whitecourt	167	64				10.1								.27							0.17													0.31	0.31	
1967 Jan	Peavine	93	36				2.8								1.40							0.53															
	Whitecourt	167	64				2.4								1.32							0.84													1.37	1.37	
Feb	Peavine	93	36				14.5								1.34							0.48															
	Whitecourt	167	64				15.8								1.17							0.75													1.23	1.23	
March	Peavine	93	36				14.2								1.51							0.54															
	Whitecourt	167	64				13.3								1.27							0.81													1.35	1.35	
April	T (°F)			17.5	21.5	29.5	26.5	23.5	31.5	38.5	33	29.5	36	38.5	36	35	33	35.5	31	30	26	28	25	26	30	37	40.5	36.5	37	38	40	37	41.5				
	DAILY P																																				
	Peavine	93	36	.07						.05																	.10						.01		0.23		
	Whitecourt	167	64		.02												.25			.02															0.29		
	WEIGHTED P																																				
	Peavine			.03						.02																	.04								0.09		
	Whitecourt				.01												.16			.01															0.18		
	AVERAGE P			.03	.01					.02							.16			.01							.04								0.27	0.23	0.04
	Remarks			S	S					S							S			S							R Thawing										

(Table 1 cont.)

PERIOD	DESCRIPTION	THIESSEN POLYGON AREA	AREA %	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	TOTAL P (In)	SNOW W.E. (In)	RAIN (In)
1967 May	T (°F)			36.5	33.5	35	41	49	50.5	43.5	40.5	37.5	37.5	40.5	43.5	51.5	55	43.5	51.5	57	48	52.5	57	62	55.5	42.5	49.5	50									
	DAILY P (In.)																																				
	Peavine	93	36														.02							.06		.06	.49	.02				.01			0.66		
	Whitecourt	167	64																								.21	.49				.04			0.74		
	WEIGHTED P																																				
	Peavine																.01							.02		.02	.18	.01							0.24		
	Whitecourt																										.13	.31				.03			0.47		
	AVERAGE P																.01							.02		.02	.31	.32				.03			0.71		0.71
	Remarks																							S		Snowmelt Recession											
Nov	T (°F)			31.5	21.5	22	20.5	25	35	37.5	35	34	29	24.5	17	17	19.5	30	30	34	31	27	31.5	32	30	31.5	30.5	9.5	.5	3.5	2.5	6.5	3.5				
	DAILY P (In.)																																				
	Peavine	93	36										.45									.02		.04		.11									0.62		
	Whitecourt	167	64	.11						.10		.01	.12	.33							.01		.15		.27	.18	.19								1.47		
	WEIGHTED P																																				
	Peavine										.16									.01		.01		.04									.22		
	Whitecourt			.07						.06		.01	.07	.21							.01		.10		.17	.12	.12								.94		
	AVERAGE P			.07						.06		.01	.23	.21							.01	.01	.10	.01	.17	.16	.12								1.16	1.02	0.14
	Remarks			S						S		S																									
							Mean Daily Temperature for the Month								Recorded Precipitation							Weighted Precipitation															
Dec	Whitecourt		100				10.3								1.34							1.34													1.34	1.34	
1968 Jan	Whitecourt		100				.4								1.54							1.54													1.44	1.54	
Feb	Peavine	93	36				17.2								.55							0.20															
	Whitecourt	167	64				15.6								.56							0.36													0.56	0.56	
March	T (°F)			35	33.5	36	43	38	41	37	27.5	30.5	16	26.5	21	19	21	19.5	20.5	24	20	26.5	21.5	32.5	45	43.5	39.5	36.5	39.5	37.5	37	29	31.5	27			
	DAILY P (In.)																																				
	Peavine	93	36			.01							.05			.60																			0.66		
	Whitecourt	167	64			.05		.01					.06			.44	.14		.13			.11											.18	.04	1.16		
	WEIGHTED P																																				
	Peavine										.02			.22																			0.24		
	Whitecourt					.03		.01					.04			.28	.09		.08			.06											.12	.03	0.74		
	AVERAGE P					.03		.01					.06			.50	.09		.08			.06											.12	.03	0.98	0.98	
	Remarks					S		S					S			S	S		S			S											S	S			
April	T (°F)			22.5	21	26	39.5	34.5	38.5	36	38.5	46	40	39	25	29.5	40	38.5	33	35.5	44.5	38.5	36	36	38.5	4 .5	41.5	42	40	48	36	33	46.5				
	DAILY P (In.)																																				
	Whitecourt		100		.05		.02						.02																				.10		0.19	0.05	0.14
	Remarks				S		S						S																	Snowmelt Recession			S				
Nov	T (°F)			38.5	26	30	27	21.5	28	16.5	19	21	27	29	33.5	33	21	12.5	7	4	8.5	26	34.5	30	33	26.5	21	12.5	28	30	29	31	20.5				
	DAILY P (In.)																																				
	Whitecourt		100								.06				.01						.09								.01						0.17	0.17	
	Remarks			Freezing																																	
							Mean Daily Temperature for the Month								Recorded Precipitation							Weighted Precipitation															
Dec	Peavine	93	36				-1.3								1.66							0.60															
	Whitecourt	167	64												1.37							0.88													1.48	1.48	
1969 Jan	Sangudo	130	50				-23.0								0.55							0.27															
	Whitecourt	130	50				-20.0								0.74							0.37													0.64	0.64	
Feb	Sangudo	130	50				4.4								0.95							0.48															
	Whitecourt	130	50				8.5								0.84							0.42													0.90	0.90	
March	Sangudo	130	50				18.4								0.40							0.20															
	Whitecourt	130	50				22.8								1.20							0.60													0.80	0.80	

(Table 1 cont.)

PERIOD	DESCRIPTION	THIESSEN POLYGON AREA	AREA %	DAY OF THE MONTH 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	TOTAL P (In)	SNOW W.E. (In)	RAIN (In)
April	T (°F)			28	27	34.5	33	36.5	35.5	43.5	35	35	40.5	44.5	47	48.5	46.5	40.5	45.5	51.0	44.5	42	41	44	46.5	31	40.5	33.5	36	41.5	49.5	49	46				
	DAILY P (In.)																																				
	Sangudo	130	50																						.07	.27	.55	.03							0.92		
	Whitecourt	130	50						.02	.06																.13	.62								0.83		
	WEIGHTED P																																				
	Sangudo																								.03	.14	.28	.01									
	Whitecourt								.01	.03																.06	.31										
	AVERAGE P								.01	.03															.03	.20	.59	.01							0.87	0.04	0.83
	Remarks							Thawing	S	R															R	S	S	R					Snowmelt Recession				
Nov	T (°F)			41	43.5	42.5	36	36	31	31.5	27.5	31	33.5	26.5	14.5	11	29	22	2	-6.5	-1	11	9	19	19	25.5	35.5	27	23	33.5	29	27.5	37				
	DAILY P (In.)																																				
	Highway	118	45											.10		.01		.74		.06	.38														1.29		
	Roman	122	47											.17		.02	.02	1.10	.01	.06	.24	.02													1.64		
	Sangudo	20	8											.14	.04			.50	.08		.22	.05													1.03		
	WEIGHTED P (In.)																																				
	Highway	118	45											.05				.33		.02	.17														.57		
	Roman	122	47											.08		.01	.01	.52		.03	.11	.01													.77		
	Sangudo	20	8											.01				.04	.01		.02														.08		
	AVERAGE P													.14		.01	.01	.89	.01	.05	.30	.01													1.42	1.42	
	Remarks									Freezing																											
							Mean Daily Temperature for the Month								Recorded Precipitation								Weighted Precipitation														
Dec	Highway	118	45				14.3								.38								0.07												0.34	0.34	
	Roman	122	47												.32								0.15														
	Sangudo	20	8				15.8								.32								0.02														
1970 Jan	Highway	118	45												.81								0.36												0.93	0.93	
	Roman	122	47												1.09								0.51														
	Sangudo	20	8				-2.3								.82								0.06														
Feb	Highway	118	45												.78								0.35												0.73	0.73	
	Roman	122	47												.69								0.32														
	Sangudo	20	8				19.9								.82								0.06														
March	Highway	118	45												1.01								0.45												0.92	0.92	
	Roman	122	47												.89								0.42														
	Sangudo	20	8				19.2								.69								0.05														
April	T (°F)			37.5	28.5	34	38	34.5	34	34.5	33	38	37	36.5	35	37.5	35	35.5	35	40	40.5	39.5	41.5	40	41	43	40.5	40	36	35	38	40	40				
	DAILY P (In.)																																				
	Highway	118	45						.06			.11			.16	.02											.06										
	Roman	122	47		.01				.06			.05			.22																						
	Sangudo	20	8									.07																									
	WEIGHTED P																																				
	Highway								.02			.05			.07	.01											.03								0.15		
	Roman				.005				.03			.02			.10																				0.19		
	Sangudo											.01																							0.01		
	AVERAGE P				.01				.05			.08			.17	.01											.03								0.35	0.24	0.11
	Remarks				S	Thawing			S			R			S	S											R										

(Table 1 cont.)

PERIOD	DESCRIPTION	THIESSEN POLYGON AREA	AREA %	DAY OF THE MONTH																															TOTAL P (In)	SNOW W.E. (In)	RAIN (In)
				1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31			
1970 May	T (°F)			50	51	45.5	42	50.5	48	44.5	50.5	60.5	46	42.5	36.5	43.5	48.5	56.5	59	48.5	6.5	48	46	48.5	51.5												
	DAILY P (In.)																																				
	Highway	118	45										.26	.11	.13																						
	Ronan	122	47										.24	.06	.06																						
	Sangudo	20	8									.25			.03																						
	WEIGHTED P																																				
	Highway												.11	.05	.06																						
	Ronan												.11	.03	.03																						
	Sangudo											.25																									
	AVERAGE P											.25	.22	.08	.09																						
	Remarks												Snowmelt Recession																								
Oct	T (°F)			38	45.5	48.5	50	36.5	34	19.5	30.5	30.5	39.5	43.5	39	38.5	40	41	42.5	38	39	43	37	40	38.5	27	32	32.5	30.5	30	29.5	39	29.5	24			
	DAILY P (In.)																																				
	Highway	118	45				.19			.05	.04				.02								.04				.28	.20							0.82		
	Ronan	122	47				.06	.06		.02	.06	.05											.04				.18	.40							0.87		
	Sangudo	20	8				.05	.08			.05	.15											.08				.30	.75							1.46		
	WEIGHTED P																																				
	Highway						.09			.02	.02				.01								.02				.12	.09							0.37		
	Ronan						.03	.03		.01	.03	.02											.02				.08	.19							0.41		
	Sangudo						.00	.01			.00	.01											.01				.02	.06							0.11		
	AVERAGE P						.12	.04		.03	.05	.03			.01								.05				.22	.34							0.89		0.89
	Remarks																												Freezing								
Nov	T (°F)			26	24.5	24.5	17.5	22.5	16.5	24	21.5	24	24.5	17	17.5	34	29.5	23	28.5	31	22.5	12.5	.5	-8.5	-5.5	-3	5	-4.5	-18	-20	-9.5	10.5	1				
	DAILY P (In.)																																				
	Highway	118	45								.10	.06		.24	.14						.24					.12	.26			.02	.02	.10	.18		1.48		
	Ronan	122	47								.10	.06		.19	.08						.20	.01				.13	.35			.02		.14	.22		1.50		
	Sangudo	20	8						.03		.02	.04		.16	.04						.10	.20				.10	.35						.10		1.14		
	WEIGHTED P																																				
	Highway										.05	.02		.11	.06						.11					.05	.12			.01	.01	.05	.08		0.67		
	Ronan										.05	.03		.09	.04						.09	.00				.06	.16			.01		.07	.10		0.70		
	Sangudo								.00		.00	.00		.01	.00						.01	.02				.01	.03						.01		0.09		
	AVERAGE P										.10	.05		.21	.10						.21	.02				.12	.31			.02	.01	.12	.19		1.46	1.46	
	Remarks																																				
							Mean Daily Temperature for the Month								Recorded Precipitation							Weighted Precipitation															
Dec	Highway	118	45												.96							0.42															
	Ronan	122	47												1.07							0.50															
	Sangudo	20	8				-5.4								0.82							0.06													0.98	0.98	
							Mean Daily Temperature for the Month								Recorded Precipitation							Weighted Precipitation															
1971 Jan	Highway	118	45												2.43							1.09															
	Ronan	122	47												2.06							0.96															
	Sangudo	20	8				-5.2								2.14							0.17													2.22	2.22	
Feb	Highway	130	45												.20							0.09															
	Ronan	130	55												.19							0.10													0.19	0.19	
March	Highway	118	45												1.29							0.58															
	Ronan	122	47												1.64							0.77															
	Sangudo	20	8				17.3								1.618							0.13													1.48	1.48	
April	T (°F)			21.5	35	37	30.5	39	43	41.5	34	36.5	30	30.5	35.5	34.5	41.5	33.5	33.5	33.5	36.5	42.5	45	46.5	46	48.5	50.5	44	40	38	37.5	37	43.5				
	DAILY P (In.)																																				
	Highway	118	45									.16	.12										.14	.04											0.46		
	Ronan	122	47									.17	.10										.08	.01											0.36		
	Sangudo	20	8									.30	.03										.06												0.39		
	WEIGHTED P																																				
	Highway											.07	.05										.06	.02											0.20		
	Ronan											.08	.05										.04												0.17		
	Sangudo											.02	.00										.01												0.03		
	AVERAGE P											.17	.10										.11	.02											0.40	0.27	0.13
	Remarks								Thawing				S	S									R	R													

(Table 1 cont.)

PERIOD	DESCRIPTION	THIESSEN POLYGON AREA	AREA %	DAY OF THE MONTH																															TOTAL P (In)	SNOW W.E. (In)	RAIN (In)
				1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31			
May	T (°F)			58	55	51.5	55	55.5	50.5	59.5	50.5	42.5	48	58.5	62	61.5	60.5	42.5	45.5	52.5	49.5	51.5	50														
	DAILY P (In.)																																				
	Highway	118	45													.02							.13														
	Roman	122	47													.12							.02														
	Sangudo	20	8													.19																					
	WEIGHTED P																																				
	Highway															.01							.06														
	Roman															.06							.01														
	Sangudo															.02																					
	AVERAGE P															0.09							.07														
	Remarks																		Snowmelt Recession																		
Nov	T (°F)			31.5	26	24	13.5	7	-4.5	5.5	22	22.5	24.5	21.5	30	29	33	22	27.5	22.5	29	34.5	35.5	34.5	31.5	15	12.5	15.5	14.5	14.5	18	20.5	11.5				
	DAILY P (In.)																																				
	Highway	118	45			.22													.05		.31	.28				.10									0.96		
	Roman	122	47			.15										.02			.01		.09	.23				.15	.01		.03						0.69		
	Sangudo	20	8			.27														.16	.28				.10				.03						0.84		
	WEIGHTED P																																				
	Highway	118	45			.10													.02		.14	.13				.04									0.43		
	Roman	122	47			.07										.01			.01		.04	.11				.07			.01						0.32		
	Sangudo	20	8			.02														.01	.02				.01										0.06		
	AVERAGE P					.19										.01			.03	.01	.20	.24			.01	.11			.01						0.81	0.81	
	Remarks			Freezing		S																															
							Mean Daily Temperature									Recorded Precipitation							Weighted Precipitation														
Dec	Highway	118	45													1.50							0.67														
	Roman	122	47													1.66							0.78														
	Sangudo	20	8				-1.1									1.34							0.11												1.56	1.56	
1972	Highway	118	45				-7.5									1.12							0.50														
Jan	Roman	122	47													.69							0.32														
	Sangudo	20	8				-1.8									.74							0.06												0.88	0.88	
Feb	Sangudo		100				1.7									1.61							1.61												1.61	1.61	
March	T (°F)			-19.5	-9.5	-16	-1	1	13.5	1.5	0	6	26.5	27.5	35.5	42	39.5	40	41	39.5	34.5	34.5	37	38	32	32.5	32	37	33.5	26.5	28.5	29	36.5	35.5			
	DAILY P (In.)																																				
	Highway	118	45		.02			.05			.10										.10	.10				.10									0.47		
	Roman	122	47		.04			.06		.02	.08	.01	.06						.05		.15	.05			.01	.18					.10				0.81		
	Sangudo	20	8	.08	.04	.03				.03	.02							.91			.12	.03				.08									1.34		
	WEIGHTED P																																				
	Highway				.01			.02			.05										.04	.05				.04									0.21		
	Roman				.02			.03		.01	.04	.00	.03						.03		.07	.02			.00	.08					.05				0.38		
	Sangudo			.01	.01	.00				.00	.00							.07			.01	.00				.07									0.10		
	AVERAGE P			.01	.04			.05		.01	.09		.03						.03		.12	.07				.19					.05				0.64	0.47	0.22
	Remarks														Thawing				S		S	S				S					S						
April	T (°F)			22.5	14	11.5	20.5	31.5	30.5	34	31	29	29	32	32.5	35.5	40	33.5	31	30.5	38	36.5	40	35.5	36	35	42	46.5	45	50.5	57.5	46	43				
	DAILY P (In.)																																				
	Highway	118	45							.24														.35											0.59		
	Roman	122	47							.18							.01							.11											0.30		
	Sangudo	20	8						.46														.24	.03											0.73		
	WEIGHTED P																																				
	Highway									.11														.16											0.27		
	Roman									.09														.05											0.14		
	Sangudo								.04														.02	.00											0.06		
	AVERAGE P								.04	.20													.02	.21											0.47	0.41	0.06
	Remarks								S	S													S	S													

(Table 1 cont.)

PERIOD	DESCRIPTION	THIESSEN POLYGON AREA	AREA %	DAY OF THE MONTH																															TOTAL P (In)	SNOW W.E. (In)	RAIN (In)
				1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31			
1972 May	T (°F)			40.5	45.5	47	43.5	43.5	43	41.5	46.0	47.5	47.5	53	59.5	63.5	47	47																			
	DAILY P (In.)																																				
	Highway	130	45				.46											.09																			
	Ronan	130	55				.12											.16																			
	WEIGHTED P																																				
	Highway																																				
	Ronan																																				
	AVERAGE P																																				
	Remarks					Snowmelt Recession																															
Oct	T (°F)			34	30.5	41	36.5	35	36.5	46.5	44	28	17.5	25.5	41.5	44	50.5	47	31	27	32.5	30.5	30	32.5	33.5	39.5	40	45	23.5	16	22.5	18	27.5	42			
	DAILY P (In.)																																				
	Highway	118	45							.08													.20	.20					.20		.04				0.72		
	Ronan	122	47							.05	.02												.15	.15	.16			.02	.04	.01	.08				0.68		
	Sangudo	20	8																				.12		.25			.05		.10					0.49		
	WEIGHTED P																																				
	Highway									.04													.09	.09					.09		.02				0.33		
	Ronan									.02	.01												.07	.07	.08			.01	.02	.00	.04				0.32		
	Sangudo																						.01		.02			.00		.10					0.04		
	AVERAGE P									.06	.01												.17	.16	.10			.01	.11	.10	.06				0.69	0.69	
	Remarks									R	S												R	R	R			R	S	S	S						
Nov	T (°F)			33	37.5	30	27	21.5	21	24	27	27	24.5	26	25.5	27	24.5	22	15	22.5	11	11.5	13	22.5	31	36.5	32	29.5	32	29	20.5	30.5	20				
	DAILY P (In.)																																				
	Highway	130	45	.40		.10		.16																								.20	.50		1.36		
	Ronan	130	55	.12	.20	.02	.01	.11					.01																			.20	.55		1.22		
	WEIGHTED P																																				
	Highway			.18		.05		.07																								.09	.22		0.61		
	Ronan			.07	.11	.01		.06					.01																			.11	.30		0.67		
	AVERAGE P			.25	.11	.06		.13					.01																			.20	.52		1.28	0.92	0.36
	Remarks					Freezing																															
						Mean Daily Temperature									Recorded Precipitation									Weighted Precipitation													
Dec	Highway	130	45												1.06									0.48													
	Ronan	130	55			2.1									1.72									0.94											1.42	1.42	
1973 Jan	Highway	130	45												0.18									0.08													
	Ronan	130	55			10.2									0.23									0.13											0.21	0.21	
Feb	Highway	130	45												0.80									0.36													
	Ronan	130	55			11.8									0.84									0.46											0.87	0.87	
	T (°F)			14.5	18.5	20	23	26	24	16.5	21.5	30.5	22	23.5	24.5	20.5	31.5	30.5	34	30	28	22	27.5	33	36	33	35.5	38.5	32	26.5	35	39.5	38.5	38			
March	DAILY P (In.)																																		0.03	0.01	0.02
	Ronan		100	.01																								.02									
	Remarks			S																							Thawing	R									
April	T (°F)			40	38.5	41.5	42.0	33.5	28.0	35.5	31	40.5	46	47.5	41.5	30.5	16	23.5	33.5	37	35	40	38.5	39	45	39.5	37	36.5	41	43.5	34	34.5	35				
	DAILY P (In.)																																				
	Highway	130	45					.20							.54	.04										.10				.52	.12	.02			1.54		
	Ronan	130	55					.15							.80	.15			.02		.06	.11		.02		.08				.25	.36	.08			2.08		
	WEIGHTED P																																				
	Highway							.09							.24	.02										.05				.24	.05	.01			0.70		
	Ronan							.08							.44	.08			.01		.03	.06		.01		.04				.14	.20	.04			1.13		
	AVERAGE P							.17							.68	.10			.01		.03	.06		.01		.09				.38	.25	.05			1.83	0.96	0.87
	Remarks							S							S	S			S		R	R		R		R				R	R	R					
Oct	T (°F)			34	41	44	39.5	41.5	39.5	34.5	38.5	36.5	40.5	42	42	35	38.5	34	36	38	44	43	43	36	34.5	34.5	34.5	38	36.5	45	43	40.5	40.5	33.5			
	DAILY P (In.)																																				
	Highway	130	45						.18	.41									.06	.15				.12	.17			.04						.38	1.51		
	Ronan	130	55						.34	.17									.03	.10				.10	.23	.03		.03						.38	1.41		
	WEIGHTED P																																				
	Highway								.08	.18									.02	.07				.06	.08			.02						.17	0.68		
	Ronan								.18	.09									.02	.06				.05	.13	.02		.02						.21	0.78		
	AVERAGE P								.26	.27									.04	.13				.11	.21	.02		.04						.38	1.46		1.46
	Remarks								R	R																											

(Table 1 cont.)

PERIOD	DESCRIPTION	THIESSEN POLYGON AREA	AREA %	DAY OF THE MONTH																															TOTAL P (In)	SNOW W.E. (In)	RAIN (In)
				1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31			
						Mean Daily Temperature									Recorded Precipitation								Weighted Precipitation														
Nov	Highway	130	45												.96								0.42														
	Roman	130	55	Freezing		4.9									1.58								0.87												1.29	1.29	
Dec	Highway	130	45												0.54								0.24														
	Roman	130	55			8.4									1.16								0.64												0.88	0.88	
1970 Jan	Highway	130	45												2.38								1.07														
	Roman	130	55			-8.8									2.43								1.34												2.41	2.41	
Feb	Highway	130	45												0.60								0.27														
	Roman	130	55			13.7									0.93								0.51												0.78	0.78	
1970 March	T (°F)			0	6	6	27.5	14.5	-10	-12	-3.5	-8.5	10	19	10.5	10	7	-2	15	21	13.5	17	17	17	-3.5	-4	15	15	14.5	18	28	22.5	30	34			
	DAILY P (In.)																																				
	Highway	130	45												.40	.20	.06						.05	.05			.16	.04							0.96		
	Roman	130	55	.02	.08									.02	.66	.49	.16	.08		.08			.08	.07		.04	.36	.22	.03						2.39		
	WEIGHTED P																																				
	Highway														.18	.09	.03						.02	.02			.07	.02							0.43		
	Roman			.01	.04									.01	.37	.27	.09	.04		.04			.04	.04		.02	.20	.12	.02						1.31		
	AVERAGE P			.01	.04									.01	.55	.36	.12	.04		.04			.06	.06		.02	.27	.14	.02						1.74	1.74	
	Remarks																																				
April	T (°F)			29	27	27	28	25	20.5	30.5	40.5	33.5	36.5	33	39	[illegible]	36	38	43.5	43.5	40	41.5	51.5	35.5	44	43.5	46	31.5	40.5	44.5	47	46	32.5				
	DAILY P (In.)																																				
	Highway	130	45					.06	.06					.28	.57					.06		.05									.21		.45		1.76		
	Roman	130	55					.11	.07					.02	.39							.09	.08						.01		.08	.07	.40		1.30		
	WEIGHTED P																																				
	Highway							.02	.02					.13	.26					.02		.02									.10		.20		0.79		
	Roman							.06	.04					.01	.21							.05	.04						.01		.03	.04	.22		0.71		
	AVERAGE P							.08	.06					.14	.47					.03		.07	.04						.01		.13	.04	.42		1.49	1.01	0.48
	Remarks							S	S	Thawing				S	S					R		R	S						R		R	R					
May	T (°F)			37	35.5	44.5	45.5	40.5	49	49	49.5	41.5	41.5	44	41	46	44	36.5	40	40	42.5	44.5	48.5														
	DAILY P (In.)																																				
	Highway	130	45					.14		.03		.79	.38	.03	.20	.07	.36	.09	.02							.58			.06	.03					2.73		
	Roman	130	55					.13		.03		.80	.22	.02	.39	.06	.06	.11	.05		.02					.21			.05						2.17		
	WEIGHTED P																																				
	Highway							.06		.01		.36	.17	.01	.09	.03	.16	.04	.01							.26			.03	.01					1.22		
	Roman							.08		.02		.44	.13	.01	.22	.03	.03	.06	.03		.01					.11			.02						1.19		
	AVERAGE P							.14		.03		.80	.30	.02	.31	.06	.19	.08	.04		.01					.37			.05	.01					2.41		2.41
	Remarks									Snowmelt Recession																											

S = Snow   R = Rain

Table 2 -Accumulative Values of

Snowfall W.E. and Rain

YEAR	PERIOD	SNOW W.E. (Inches)	RAIN (Inches)	ACCUMULATED SNOW W.E. (Inches)	ACCUMULATED RAIN (Inches)	TOTAL PRECIPITATION (Inches)
1963-64	Nov 3	0		0		
	Nov 30	1.06		1.06		
	Dec 31	0.48		1.54		
	Jan 31	0.48		2.02		
	Feb 29	0.75		2.77		
	Mar 29	0.85	0	3.62	0	
	April 24	0.24	0.65	3.86	0.65	4.51
1964-65	Nov 8	0		0		
	Nov 30	1.88		1.88		
	Dec 31	0.56		2.44		
	Jan 31	2.33		4.77		
	Feb 28	1.64		6.41		
	April 2	0.16	0	6.57	0	
	April 20	0.60	0.14	7.17	0.14	
	April 30	0	0.02	7.17	0.16	
	May 14	0	0.02	7.17	0.18	7.35
1965-66	Nov 1	0		0		
	Nov 30	0.96		0.96		
	Dec 31	0.69		1.65		
	Jan 31	1.46		3.11		
	Feb 28	0.82		3.93		
	Mar 24	0.60	0	4.53	0	
	May 8	1.[illegible]	0.76	5.56	0.76	6.32
1966-67	Nov 1	0		0		
	Nov 30	1.36		1.36		
	Dec 31	0.31		1.67		
	Jan 31	1.37		3.04		
	Feb 28	1.27		4.31		
	Mar 31	1.35		5.66		
	April 22	0.23	0.04	5.89	0.04	
	May 22	0	0.03	5.89	0.07	5.96
1967-68	Nov 10	0		0		
	Nov 30	1.02		1.02		
	Dec 31	1.34		2.36		
	Jan 31	1.54		3.90		
	Feb 29	0.56		4.46		
	Mar 31	0.98		5.44		
	April 2	0.05	0	5.49	0	
	April 30		0.14	5.49	0.14	5.63
1968-69	Nov 7	0		0		
	Nov 30	0.17		0.17		
	Dec 31	1.48		1.65		
	Jan 31	0.64		2.29		
	Feb 28	0.90		3.19		
	April 2	0.80	0	3.99	0	
	April 21	0.01	0.03	4.01	0.03	4.04

(Table 2 Cont.)

YEAR	PERIOD	SNOW W.E. (Inches)	RAIN (Inches)	ACCUMULATED SNOW W.E. (Inches)	ACCUMULATED RAIN (Inches)	TOTAL PRECIPITATION (Inches)
1969-70	Nov 5	0		0		
	Nov 30	1.42		1.42		
	Dec 31	0.34		1.76		
	Jan 31	0.93		2.69		
	Feb 28	0.73		3.42		
	Mar 31	0.92		4.34		
	April 2	0.01	0	4.35	0	
	May 8	0.24	0.11	4.59	0.11	4.70
1970-71	Oct 26	0		0		
	Nov 30	1.46		1.46		
	Dec 31	0.98		2.44		
	Jan 31	2.22		4.66		
	Feb 28	0.19		4.85		
	April 4	1.48		6.33		
	April 10	0.27	0	6.6	0	
	May 12	0	0.13	6.6	0.13	6.73
1971-72	Nov 1	0		0		
	Nov 30	0.81		0.81		
	Dec 31	1.56		2.37		
	Jan 31	0.88		3.25		
	Feb 29	1.61		4.86		
	Mar 11	0.23	0	5.09	0	
	Mar 29	0.24	0.22	5.33	0.22	
	May 2	0.41	0.06	5.74	0.28	6.02
1972-73	Nov 3	0		0		
	Nov 30	0.92		0.92		
	Dec 31	1.42		2.34		
	Jan 31	0.21		2.55		
	Feb 28	0.82	0	3.37	0	
	Mar 31	0.01	0.02	3.38	0.02	
	April 28	0.96	0.19	4.34	0.21	4.55
1973-74	Nov 1	0		0		
	Nov 30	1.29		1.29		
	Dec 31	0.88		2.17		
	Jan 31	2.41		4.58		
	Feb 28	0.78		5.36		
	Mar 31	1.74		7.1		
	April 7	0.14	0	7.24	0	
	May 4	0.87	0.48	8.11	0.48	8.59

APPENDIX - B

SOIL MOISTURE INDICES FOR PADDLE RIVER BASIN

TABLE 3 - Base Flow Storage Before Freeze-up

YEAR (1)	BASE FLOW BEFORE FREEZE-UP Q cfs (2)	$\frac{Q'-Q}{\ln kr}$ (3)	$\frac{-Q'}{\ln krb}$ (4)	BASE FLOW STORAGE S_b cfs-days (5)=(3)+(4)	BASE FLOW STORAGE S_b Inches (6)=$\frac{(5)}{260}$ x 0.0372
1963	1.4	-	1.02	1.02	0.0001
1964	15.0	9.54	3.44	12.98	0.0018
1965	13.8	8.43	3.44	11.87	0.0017
1966	12.0	6.76	3.44	10.20	0.0014
1967	1.5	-	1.10	1.10	0.0001
1968	5.1	0.37	3.44	3.81	0.0005
1969	18.3	12.61	3.44	16.05	0.0023
1970	3.4	-	2.48	2.48	0.0003
1971	13.0	7.69	3.44	11.13	0.0016
1972	5.0	0.28	3.44	3.72	0.0005
1973	27.2	20.85	3.44	24.29	0.0035

Note: In the above Table

$\ln kr = \ln 0.340 = -1.0788$
$\ln krb = \ln 0.255 = -1.366$
$Q' = Q$ if $Q < 4.7$ cfs
$Q' = 4.7$ cfs if $Q > 4.7$ cfs

Table 4 -Antecedent Precipitation Index (API) Before Freeze-up

PERIOD		WEIGHTED RAINFALL % OF RECORDED PEAVINE (36%)	WEIGHTED RAINFALL % OF RECORDED WHITECOURT (64%)	AVERAGE MONTHLY P (In)	API Constant K'	$K'P$
1963	May	0.38	0.90	1.28	0.0156	0.02
	June	0.53	1.33	1.86	0.0312	0.058
	July	1.52	1.79	3.31	0.0625	0.206
	Aug	0.65	1.62	2.27	0.125	0.283
	Sept	0.36	0.66	1.02	0.25	0.255
	Oct	0.19	0.41	0.60	0.5	0.30

$API_{(o)} = \Sigma K'P = 1.123$

Nov	1	2	3
	1.01	0.91	0.82

API on Nov 3, 1963 = 0.82

PERIOD		PEAVINE (36%)	WHITECOURT (64%)	P (In)	K'	$K'P$
1964	May	1.13	2.55	3.68	0.0156	0.0574
	June	.89	2.03	2.92	0.0312	0.0911
	July	2.06	3.90	5.96	0.0625	0.3725
	Aug	1.74	3.34	5.08	0.125	0.6350
	Sept	.56	.99	1.55	0.25	0.3875
	Oct	.12	.20	.32	0.5	0.16

$API_{(o)} = \Sigma K'P = 1.7035$

Nov	1	2	3	4	5	6	7
API	1.53	1.38	1.24	1.11	1.0	0.90 $\underline{0.02}$(P) 0.92	0.83

API Nov 7, 1964 = 0.83

PERIOD		PEAVINE (36%)	WHITECOURT (64%)	P (In)	K'	$K'P$
1965	June	2.48	4.32	6.80	0.0312	0.212
	July	.88	2.05	2.93	0.0625	0.183
	Aug	.94	3.17	4.11	0.125	0.514
	Sept	.37	.81	1.18	0.25	0.295
	Oct	.02	.06	.08	0.5	0.040

$API_{(o)} = \Sigma K'P = 1.244$

API on Nov. 1, 1965 = 1.244 x 0.90 + 0.01 = 1.13

PERIOD		PEAVINE (36%)	WHITECOURT (64%)	P (In)	K'	$K'P$
1966	June	.65	1.08	1.73	0.0312	0.144
	July	1.85	3.37	5.22	0.0625	0.327
	Aug	1.16	2.60	3.76	0.125	0.471
	Sept	.07	.16	.23	0.25	0.058
	Oct	.07	.33	.40	0.5	0.20

API on Oct. 31, 1966 = $\Sigma K'P$ = 1.20

PERIOD		PEAVINE (36%)	WHITECOURT (64%)	P (In)	K'	$K'P$
1967	June	.44	.92	1.36	0.0312	0.0424
	July	.24	.45	.69	0.0625	0.0431
	Aug	.15	.34	.49	0.125	0.0612
	Sept	.07	.35	.42	0.25	0.105
	Oct	.56	1.68	2.24	0.5	1.12

$API_{(o)} = \Sigma K'P = 1.3717$

Nov	1	2	3	4	5	6	7	8	9
	1.23 $\underline{0.07}$(P) 1.30	1.17	1.05	0.94	.85	.76	.68 $\underline{.06}$(P) .74	.67	.60 $\underline{.01}$(P) .61

API on Nov 9, 1967=0.61

PERIOD		PEAVINE (36%)	WHITECOURT (64%)	P (In)	K'	$K'P$
1968	May	.80	1.44	2.24	0.0156	0.034
	June	.94	1.85	2.79	0.0312	0.087
	July	1.23	1.63	2.86	0.0625	0.178
	Aug	1.24	8.41	3.65	0.125	0.456
	Sept	.27*	.43	.70	0.25	0.175
	Oct	.60*	.38	.98	0.5	0.490

*Sangudo Values API on Oct. 31, 1968 = $\Sigma K'P$ = 1.42

(Table 4 Cont.)

PERIOD	WEIGHTED RAINFALL % OF RECORDED SANGUDO (50%)	WHITECOURT (50%)	AVERAGE MONTHLY P (in.)	API Constant K′	K′P
1969 May	.35	.40	.75	0.0156	0.01
June	1.78	1.41	3.19	0.0312	0.10
July	1.63	2.69	4.32	0.0625	0.27
Aug	3.01	2.38	5.39	0.125	0.67
Sept	2.04	1.76	3.80	0.25	0.95
Oct	0.56	0.52	1.08	0.5	0.54

(Highway) (Ronan)

Nov	1	2	3	4	5
API	2.29	2.43	2.28	2.05	1.84
	.41	.10(P)			
	2.70	2.53			

$API_{(o)} = \Sigma K'P = 2.54$

API on Nov 5, 1969 = 1.84

PERIOD	HIGHWAY 45%	RONAN 47%	SANGUDO 8%			
1970 June	1.49	1.33	0.19	3.01	0.0312	0.094
July	3.47	1.99	0.25	5.71	0.0625	0.358
Aug	0.62	0.68	0.16	1.46	0.125	0.183
Sept	0.35	0.29	0.04	0.68	0.25	0.170
Oct	0.37	0.41	0.11	0.89	0.5	0.445

API on Oct 31, 1970 = $\Sigma K'P$ = 1.25

1971 June	3.04	2.73	0.54	6.31	0.0312	0.197
July	3.40	2.90	0.49	6.79	0.0625	0.425
Aug	0.50	0.77	0.12	1.39	0.125	0.175
Sept	1.24	1.08	0.09	2.41	0.25	0.603
Oct	0.12	0.13	0.01	0.26	0.5	0.130

API on Oct 31, 1971 = $\Sigma K'P$ = 1.53

1972 May	1.01	1.01		2.02	0.0156	0.031
June	2.49	2.52	0.31	5.32	0.0312	0.166
July	0.92	1.14	0.20	2.26	0.0625	0.141
Aug	0.86	1.26	-	2.12	0.125	0.265
Sep	0.56	0.91	-	1.47	0.25	0.367
Oct	0.32	0.32	0.04	0.68	0.5	0.340

$API_{(o)} = \Sigma K'P = 1.31$

Nov	1	2
	1.18	1.29
	0.25(P)	0.11(P)
	1.43	1.40

API on Nov 2, 1972 = 1.40

PERIOD	HIGHWAY (45%)	RONAN (55%)			
1973 May	0.74	1.47	2.21	0.0156	0.033
June	2.64	3.21	5.85	0.0312	0.181
July	1.09	1.26	2.35	0.0625	0.146
Aug	2.42	2.73	5.15	0.125	0.643
Sept	1.08	1.01	2.09	0.25	0.522
Oct	0.68	0.37	1.05	0.5	0.525

API on Oct 31, 1973 = $\Sigma K'P$ = 2.05

Table 5-October Basin Recharge Coefficient for Paddle River Basin

YEAR	OCTOBER PRECIPITATION P_o(In)	OCTOBER RUNOFF R_o(In)	$P_o - R_o$	BASIN RECHARGE COEFFICIENT $BRC = \frac{P_o - R_o}{P_o}$
1963	0.60	0.004	0.596	0.99
1964	0.32	0.125	0.195	0.61
1965	0.08	0.080	0	0
1966	0.40	0.046	0.354	0.88
1967	2.24	0.001	2.239	0.99
1968	0.98	0.020	0.96	0.97
1969	1.08	0.173	0.907	0.84
1970	0.89	0.030	0.86	0.96
1971	0.26	0.060	0.20	.077
1972	0.68	(M)	-	-
1973	1.05	0.141	0.909	0.86

APPENDIX-C

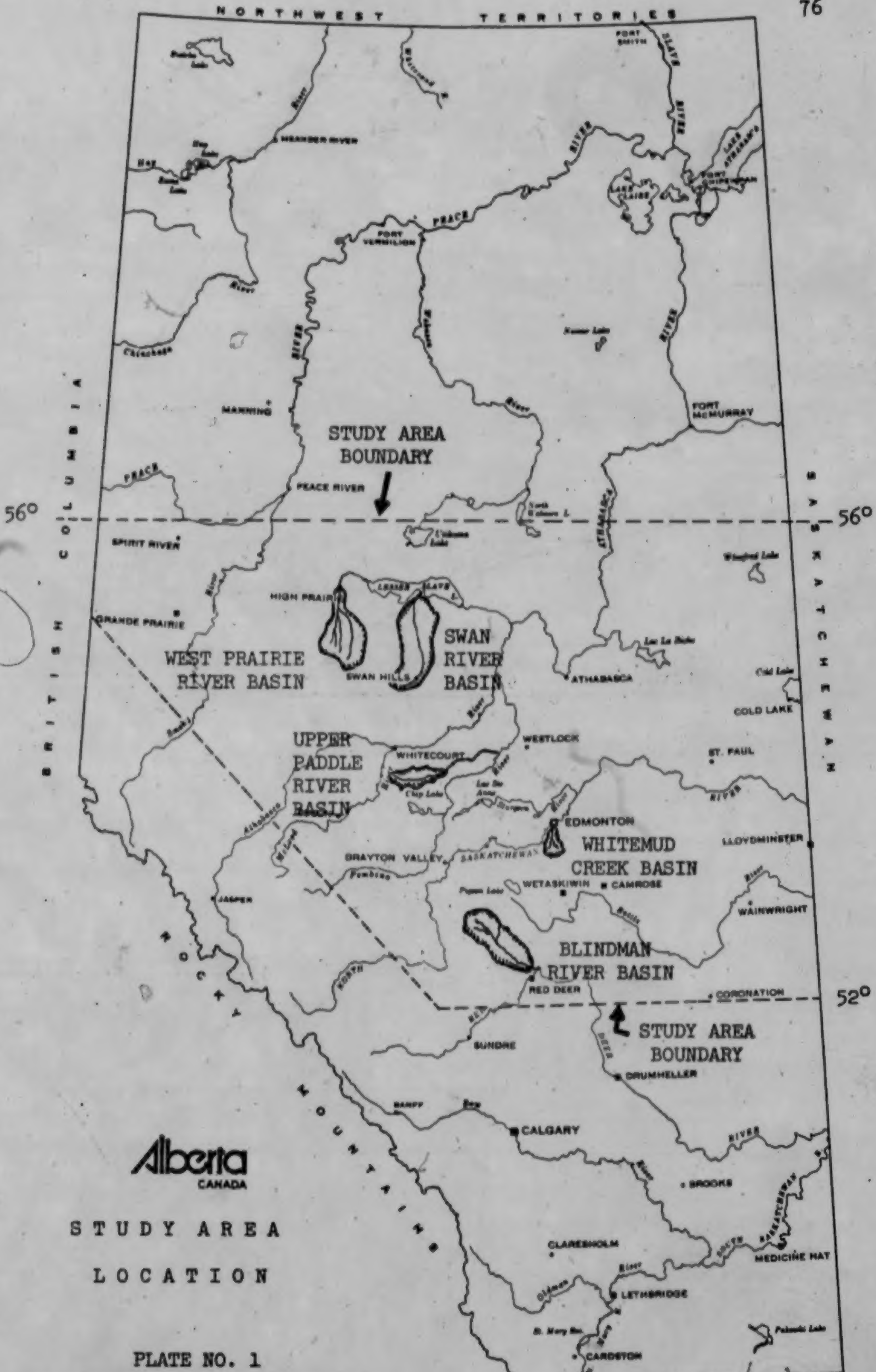
SNOWMELT RUNOFF FOR PADDLE RIVER BASIN

Table No. 6 -Computations for Snowmelt Runoff

DURATION	MEAN DAILY FLOW		NO OF DAYS	TOTAL RUNOFF IN SNOWMELT PERIOD Ins/Sq mile	RAINFALL RUNOFF Ins/Sq mile	SNOWMELT RUNOFF, S_r Ins/Sq mile
	cfs	cfs/Sq mile				
1964						
Mar 1-31	8.06	0.031	31	0.036		
Apr 1-10	83.10	0.320	10	0.120		
11-20	152.30	0.586	10	0.220		
21-25	46.38	0.178	5	0.033		
26-30	-	0.016	5	0.003		
				0.412	0.092	0.32
1965						
Mar 1-31	4.10	0.016	31	0.018		
Apr 1-12	13.89	0.053	12	0.024		
13-21	423.55	1.629	9	0.55		
22-30	1586.11	6.100	9	2.059		
May 1-15	333.33	1.282	15	0.722		
16-23	-	0.089	8	0.027		
				3.400	0.013	3.387
1966						
Mar 1-31	46.3	0.178	31	0.205		
Apr 1-13	560.84	2.157	13	1.051		
14-22	233.33	0.897	9	0.303		
23-26	227.25	0.874	4	0.131		
May27- 9	164.67	0.633	13	0.309		
May10-18	-	0.045	9	0.015		
				2.014	0.044	1.97
1967						
Mar 1-31	1.11	0.004	31	0.005		
Apr 1-12	1.50	0.006	12	0.003		
13-23	166.85	0.642	11	0.024		
24-30	261.57	1.006	7	0.264		
May 1-22	185.70	0.714	22	0.589		
23-31	-	0.025	9	0.008		
				0.893	0.010	0.883
1968						
Mar 1-31	86.10	0.331	31	0.382		
Apr 1-30	34.80	0.134	30	0.149		
May 1- 7	-	0.011	7	0.003		
				0.534	0.019	0.515
1969						
Mar 1-31	3.00	0.0115	31	0.013		
Apr 1- 6	16.60	0.064	6	0.014		
7-24	528.83	2.034	18	1.373		
25-30	-	0.16	6	0.036		
May 1- 4	-	0.004	4	0.001		
				1.437	0.004	1.433

(Table 6 cont.)

DURATION	MEAN DAILY FLOW		NO OF DAYS	TOTAL RUNOFF IN SNOWMELT PERIOD Ins/Sq mile	RAINFALL RUNOFF Ins/Sq mile	SNOWMELT RUNOFF, S_r Ins/Sq mile
	cfs	cfs/ Sq mile				
1970						
Mar22-31	44.90	0.173	10	0.064		
Apr 1- 8	156.62	0.602	8	0.180		
9-15	250.85	0.965	7	0.253		
16-30	222.93	0.857	15	0.482		
May 1- 9	72.20	0.277	9	0.094		
10-18	-	0.027	9	0.009		
				1.082	0.007	1.075
1971						
Mar 1-31	7.34	0.028	31	0.032		
Apr 1-20	206.76	0.795	20	0.596		
21-22	1575.00	6.057	2	0.454		
23-30	829.50	3.190	8	0.957		
May 1-15	123.18	0.474	15	0.266		
16-24	-	0.240	9	0.008		
				2.313	0.07	2.243
1972						
Mar 1-31	40.20	0.155	31	0.180		
Apr 1-30	302.00	1.161	30	1.307		
May 1- 2	238.00	0.915	2	0.069		
3- 6	-	0.342	4	0.052		
7-13	-	0.008	7	0.002		
				1.610	0.04	1.57
1973						
Mar 1-31	28.3	0.109	31	0.126		
Apr 1-28	136.50	0.525	28	0.551		
29-30	-	0.375	2	0.028		
May 1- 8	-	0.021	8	0.006		
				0.771	0.027	0.744
1974						
Mar 1-31	4.30	0.016	31	0.019		
Apr 1-30	993.00	3.820	30	4.300		
May 1- 6	414.66	1.595	6	0.358		
7-10	-	0.500	4	0.075		
11-18	-	0.015	8	0.004		
				4.756	0.07	4.68

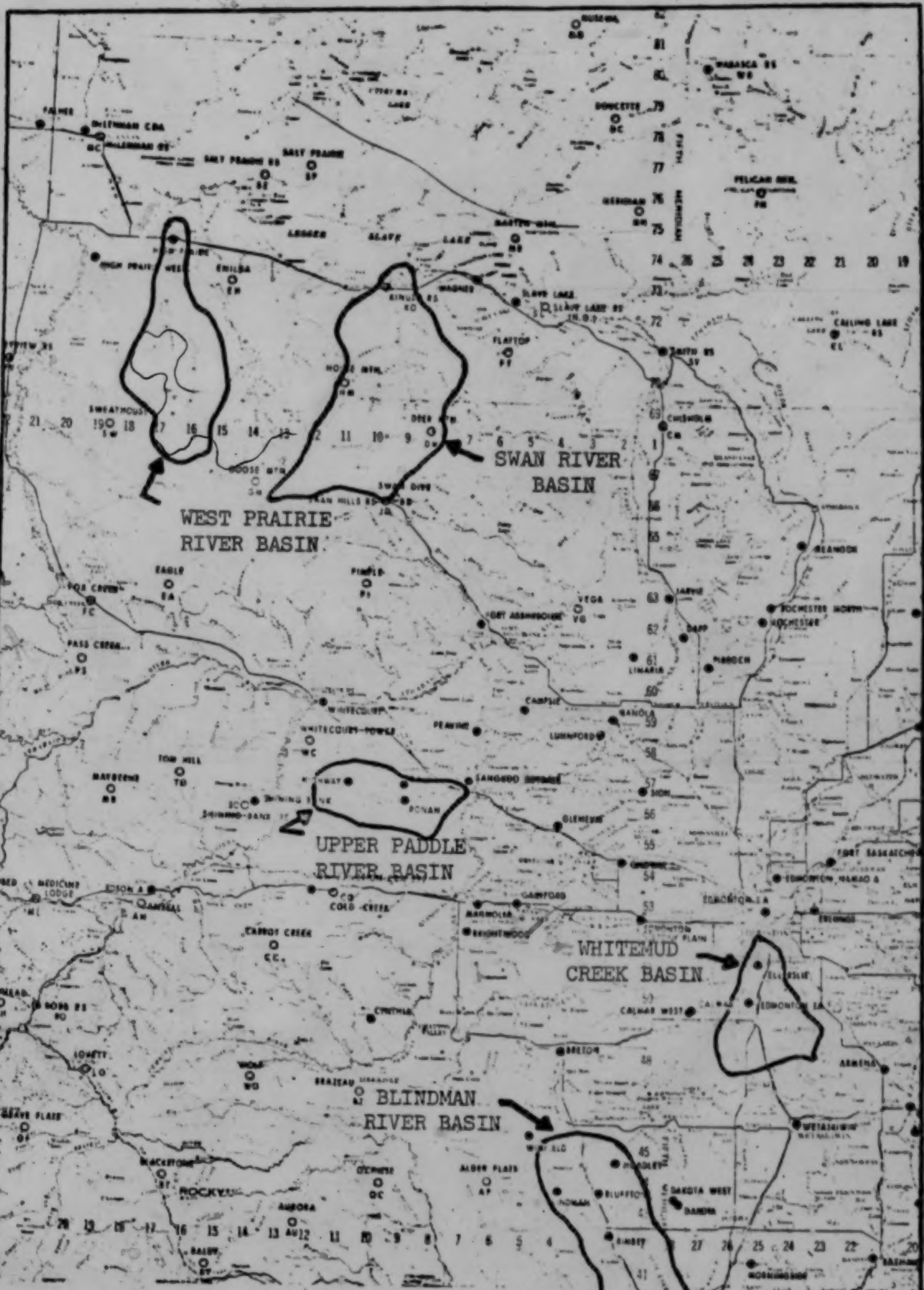

NORTHWEST TERRITORIES
BRITISH COLUMBIA
SASKATCHEWAN
MONTANA
ROCKY MOUNTAINS
FORT SMITH
SLAVE RIVER
MEANDER RIVER
PEACE RIVER
FORT VERMILION
LAKE CLAIRE
FORT CHIPEWYAN
LAKE ATHABASCA
MANNING
FORT McMURRAY
STUDY AREA BOUNDARY
56°
SPIRIT RIVER
GRANDE PRAIRIE
HIGH PRAIRIE
LESSER SLAVE L.
SWAN HILLS
WEST PRAIRIE RIVER BASIN
SWAN RIVER BASIN
ATHABASCA
Lac La Biche
Cold Lake
COLD LAKE
WESTLOCK
ST. PAUL
UPPER PADDLE RIVER BASIN
WHITECOURT
Chip Lake
Lac Ste Anne
EDMONTON
WHITEMUD CREEK BASIN
LLOYDMINSTER
DRAYTON VALLEY
SASKATCHEWAN
Pembina
JASPER
Pigeon Lake
WETASKIWIN
CAMROSE
Battle
WAINWRIGHT
BLINDMAN RIVER BASIN
RED DEER
CORONATION
52°
STUDY AREA BOUNDARY
SUNDRE
DRUMHELLER
BANFF
Bow
CALGARY
RIVER
BROOKS
CLARESHOLM
SOUTH SASKATCHEWAN
MEDICINE HAT
Oldman
LETHBRIDGE
St. Mary Res.
CARDSTON
Pakowki Lake
Alberta
CANADA

STUDY AREA

LOCATION

PLATE NO. 1

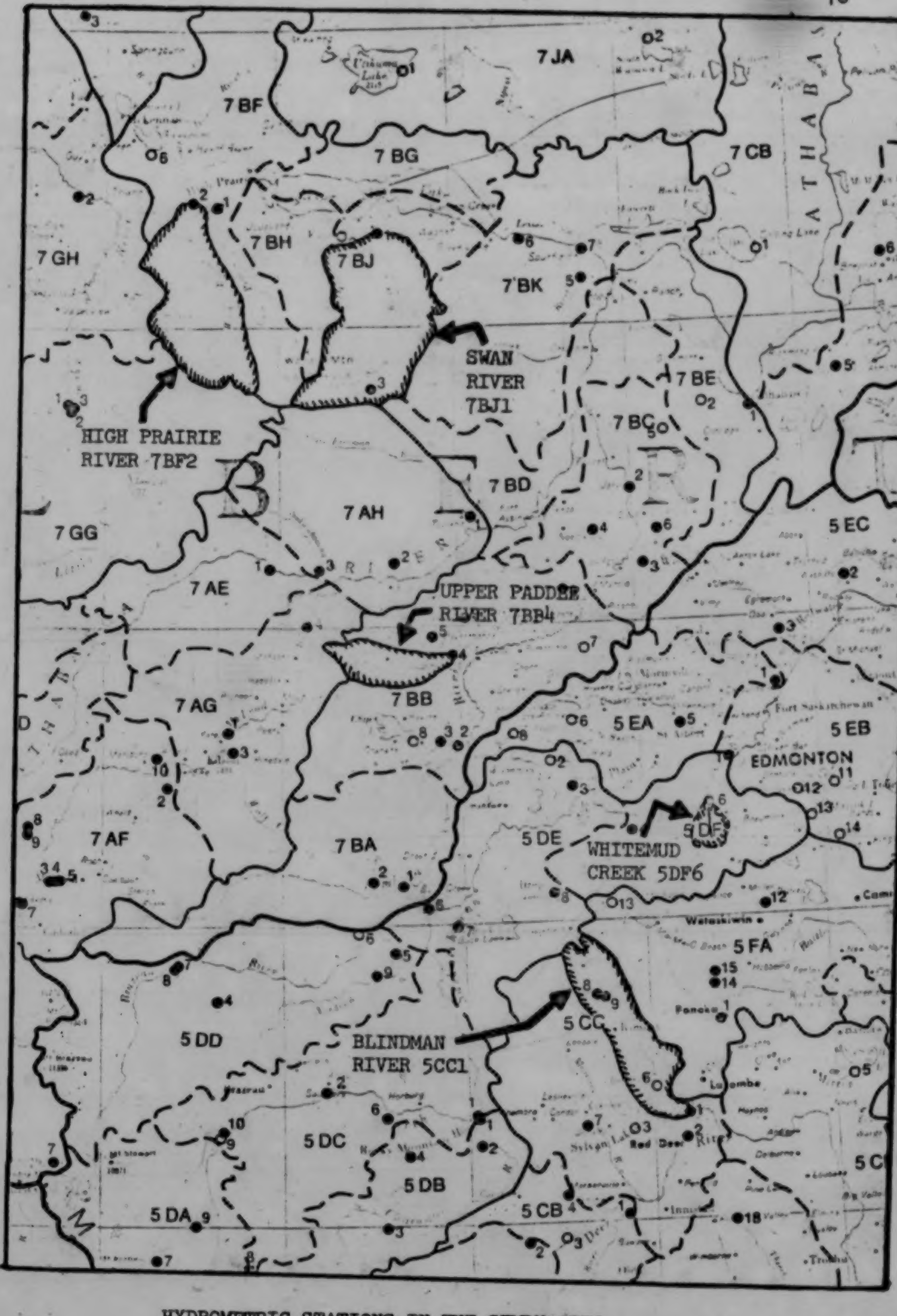
PRODUCED BY SURVEYS BRANCH, DEPARTMENT OF HIGHWAYS AND TRANSPORT, EDMONTON. DO NOT REPRODUCE


WEST PRAIRIE RIVER BASIN
SWAN RIVER BASIN
UPPER PADDLE RIVER BASIN
WHITEMUD CREEK BASIN
BLINDMAN RIVER BASIN
ROCKY

CLIMATOLOGICAL STATIONS

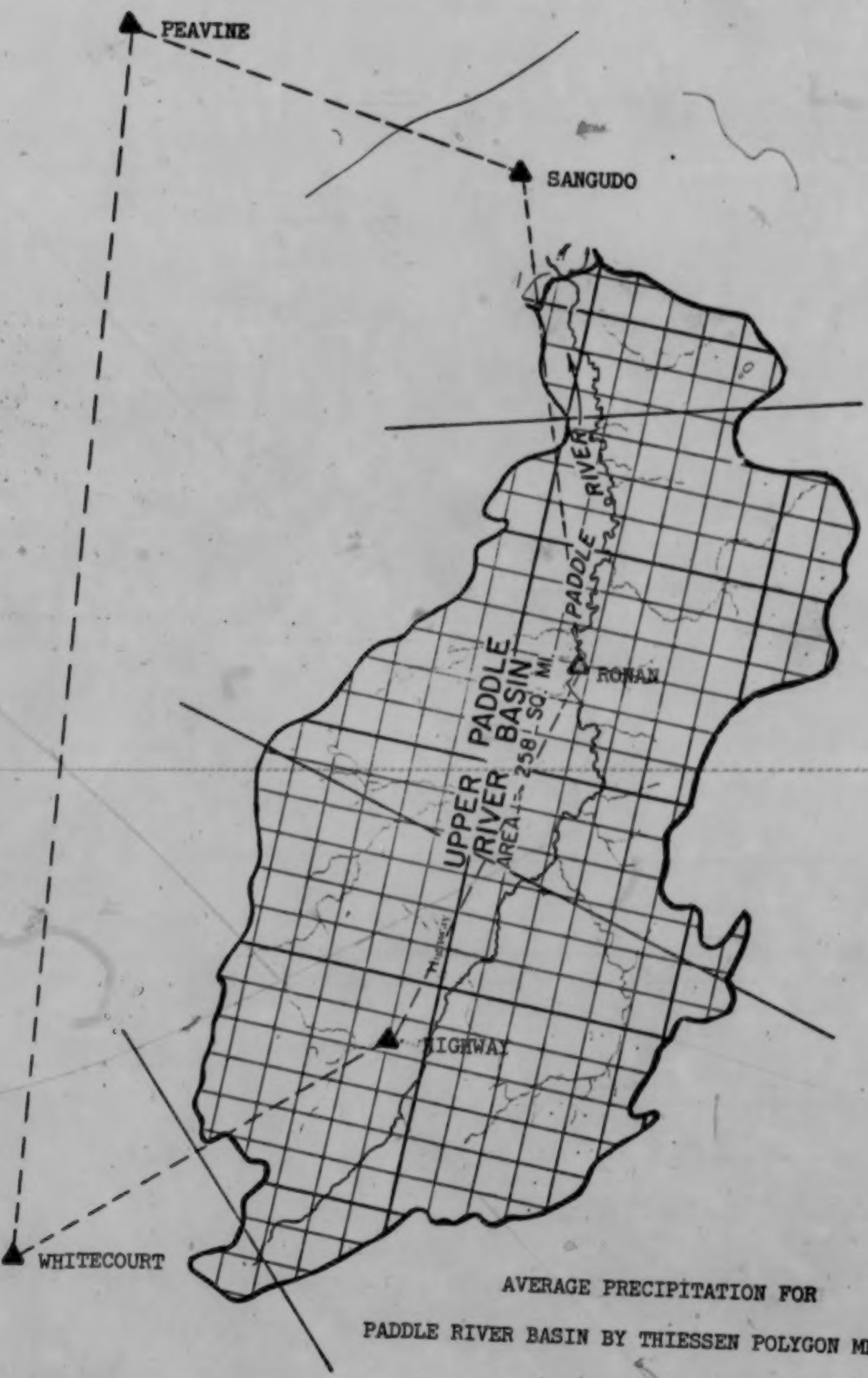
- ● Atmospheric Environment Service CLIMAT or SYNOPTIC STATIONS reporting all year.
- ◉ Alberta Forest Service RANGER STATIONS reporting all year.
- ○ Alberta Forest Service LOOKOUTS and RANGER STATIONS reporting during summer only.

PLATE NO. 2


7 JA
7 BF
7 BG
7 CB
7 GH
7 BH
7 BJ
7 BK
SWAN
RIVER
7BJ1
HIGH PRAIRIE
RIVER 7BF2
7 BE
7 BC
7 BD
7 AH
7 GG
5 EC
7 AE
UPPER PADDLE
RIVER 7BB4
7 BB
7 AG
5 EA
5 EB
EDMONTON
7 AF
7 BA
5 DE
WHITEMUD
CREEK 5DF6
5 DF
5 FA
5 DD
5 CC
BLINDMAN
RIVER 5CC1
5 DC
5 DB
5 DA
5 CB
5 C
Red Deer
Wetaskiwin
Ponoka
Lacombe

HYDROMETRIC STATIONS IN THE STUDY AREA

PLATE NO. 3


PEAVINE
SANGUDO
PADDLE RIVER
UPPER PADDLE RIVER BASIN
AREA = 258 SQ. MI.
RONAN
HIGHWAY
WHITECOURT

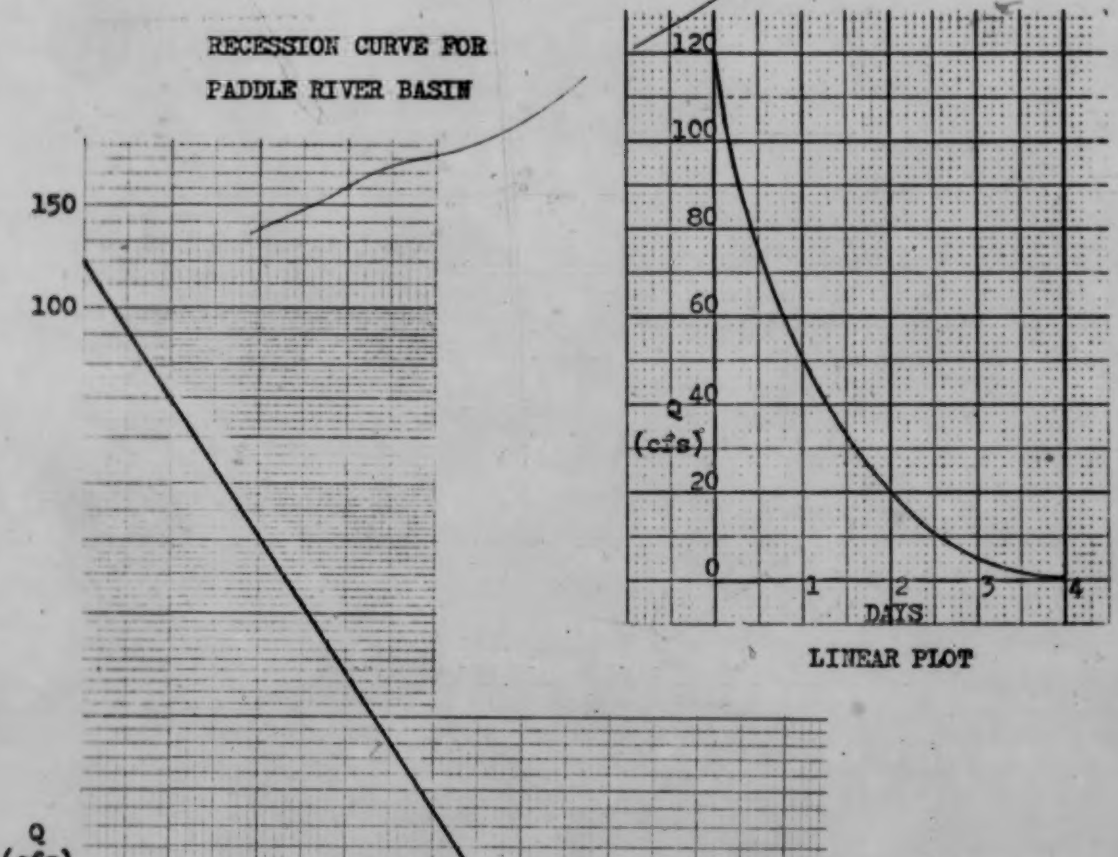
AVERAGE PRECIPITATION FOR

PADDLE RIVER BASIN BY THIESSEN POLYGON METHOD

PLATE NO. 4

80

RECESSION CURVE FOR PADDLE RIVER BASIN

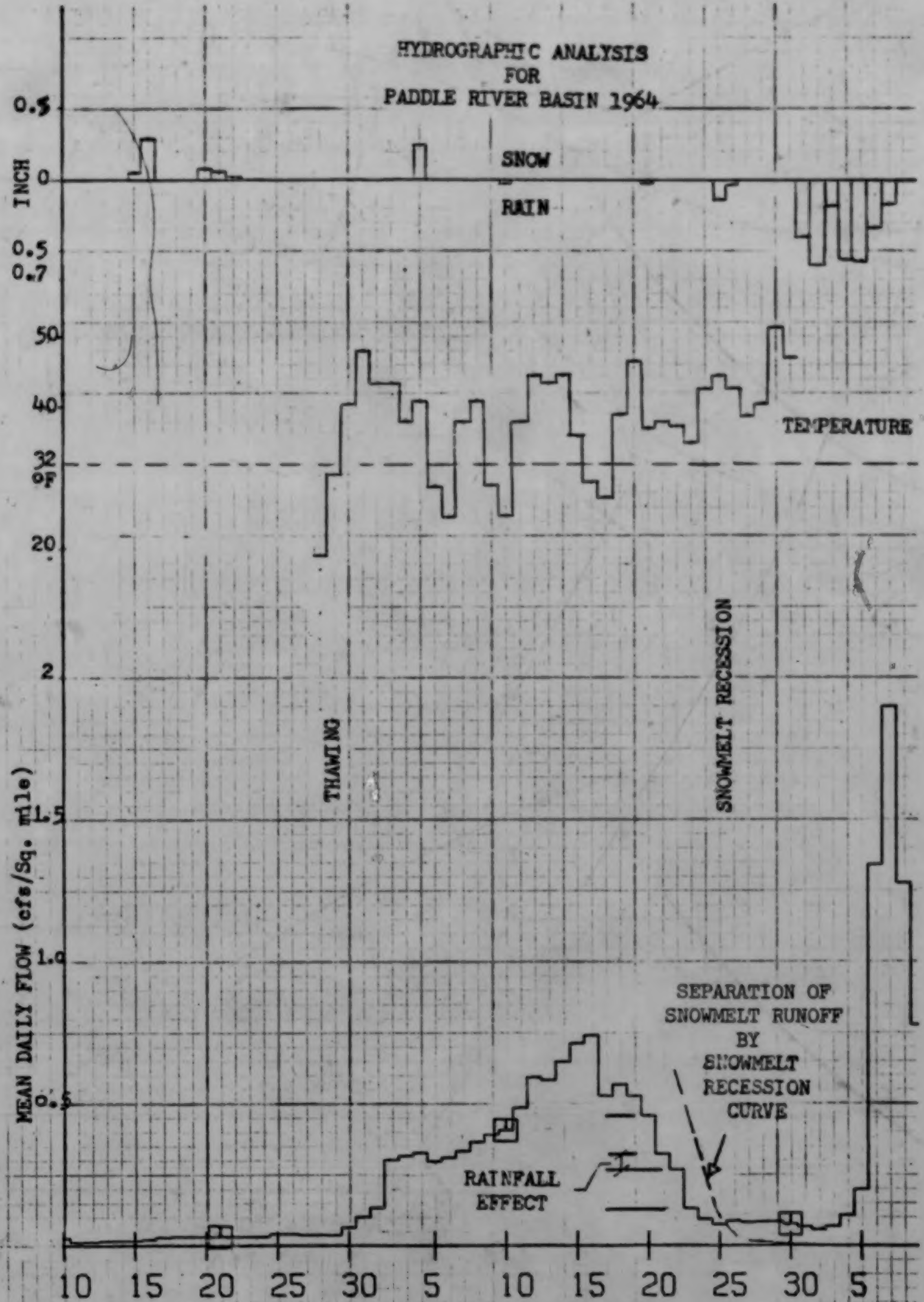


LINEAR PLOT

DAYS

SEMI-LOG PLOT

PLATE NO. 5


HYDROGRAPHIC ANALYSIS
FOR
PADDLE RIVER BASIN 1964
0.5
0
INCH
SNOW
RAIN
0.5
0.7
50
40
32
°F
20
TEMPERATURE
THAWING
SNOWMELT RECESSION
2
1.5
1.0
0.5
MEAN DAILY FLOW (cfs/Sq. mile)
SEPARATION OF
SNOWMELT RUNOFF
BY
SNOWMELT
RECESSION
CURVE
RAINFALL
EFFECT
10
15
20
25
30
5
10
15
20
25
30
5
MARCH
1964
APRIL
PLATE NO. 6

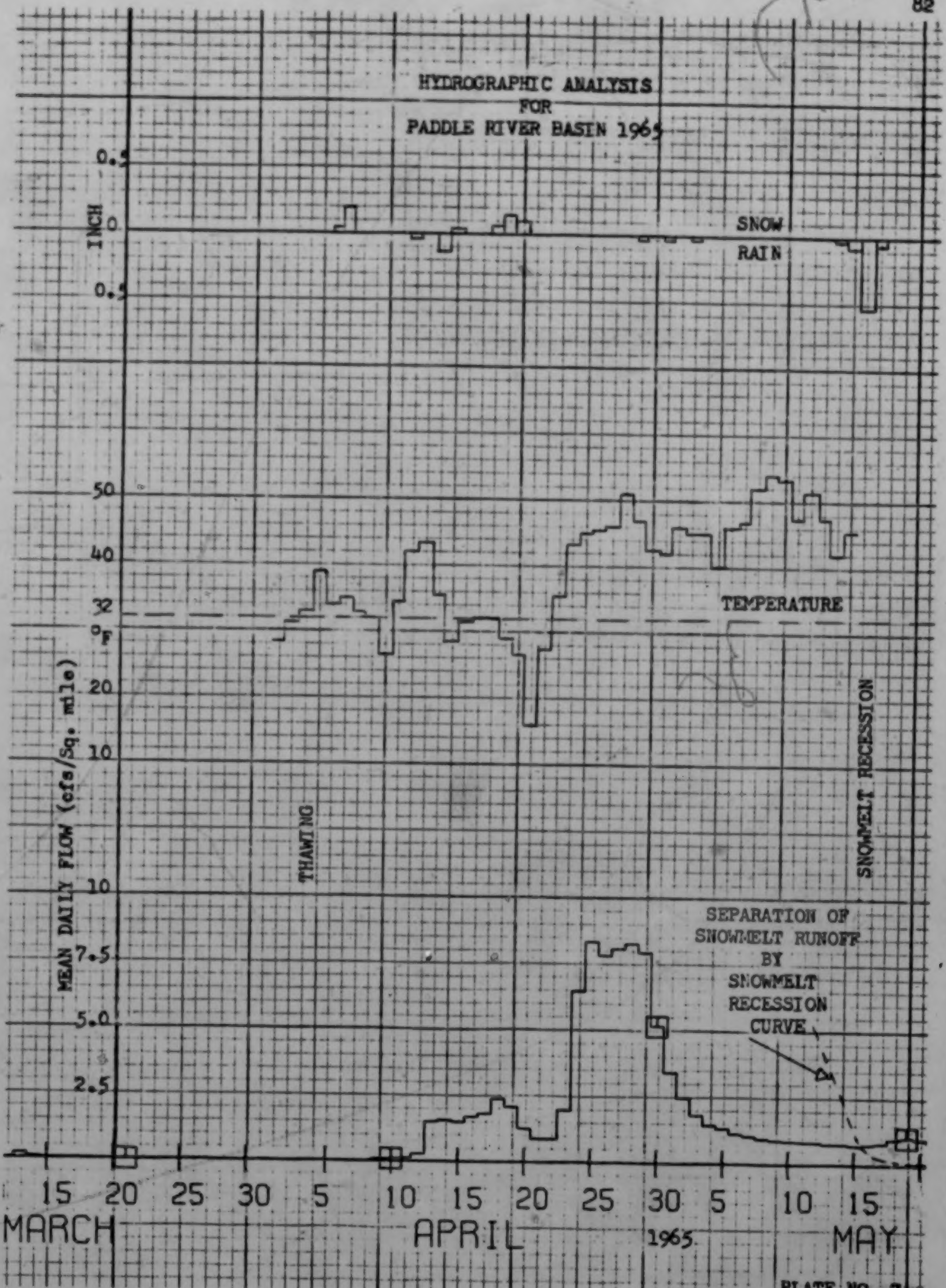
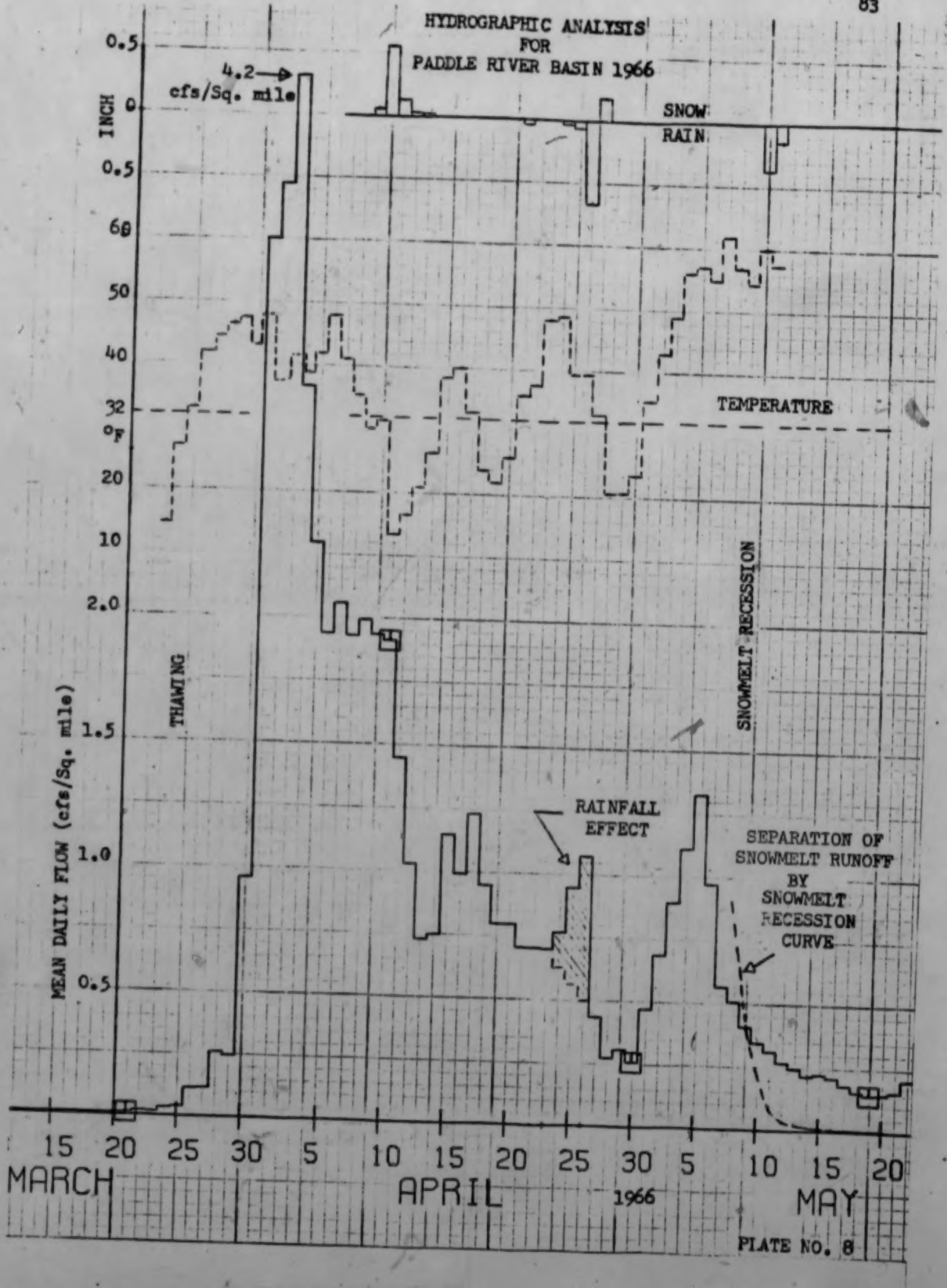

HYDROGRAPHIC ANALYSIS
FOR
PADDLE RIVER BASIN 1965
INCH
0.5
0.
0.5
SNOW
RAIN
50
40
32
°F
20
10
TEMPERATURE
MEAN DAILY FLOW (cfs/Sq. mile)
10
7.5
5.0
2.5
THAWING
SNOWMELT RECESSION
SEPARATION OF
SNOWMELT RUNOFF
BY
SNOWMELT
RECESSION
CURVE
15
20
25
30
5
10
15
20
25
30
5
10
15
MARCH
APRIL
1965
MAY

PLATE NO. 7



HYDROGRAPHIC ANALYSIS FOR PADDLE RIVER BASIN 1966

PLATE NO. 8

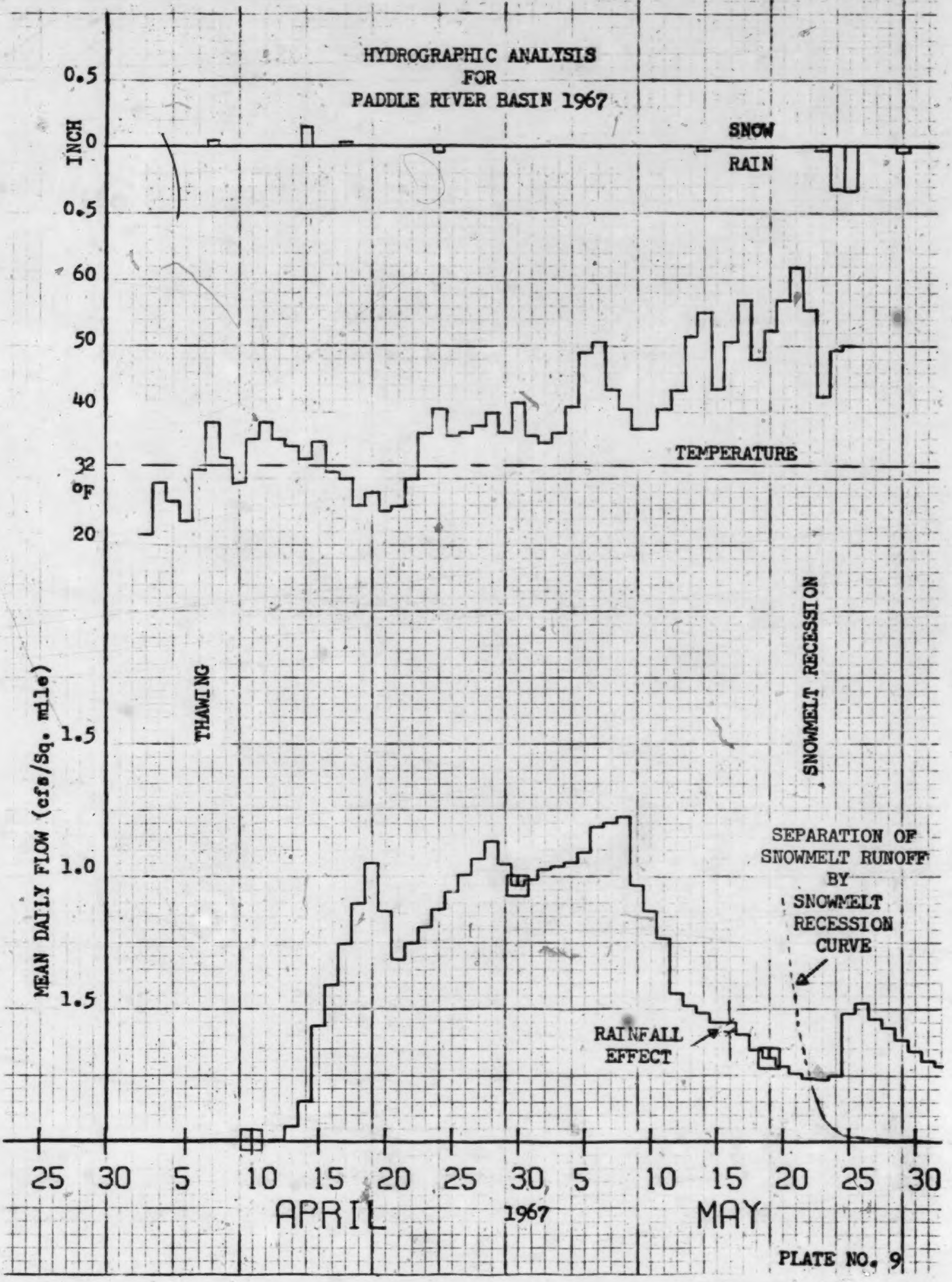
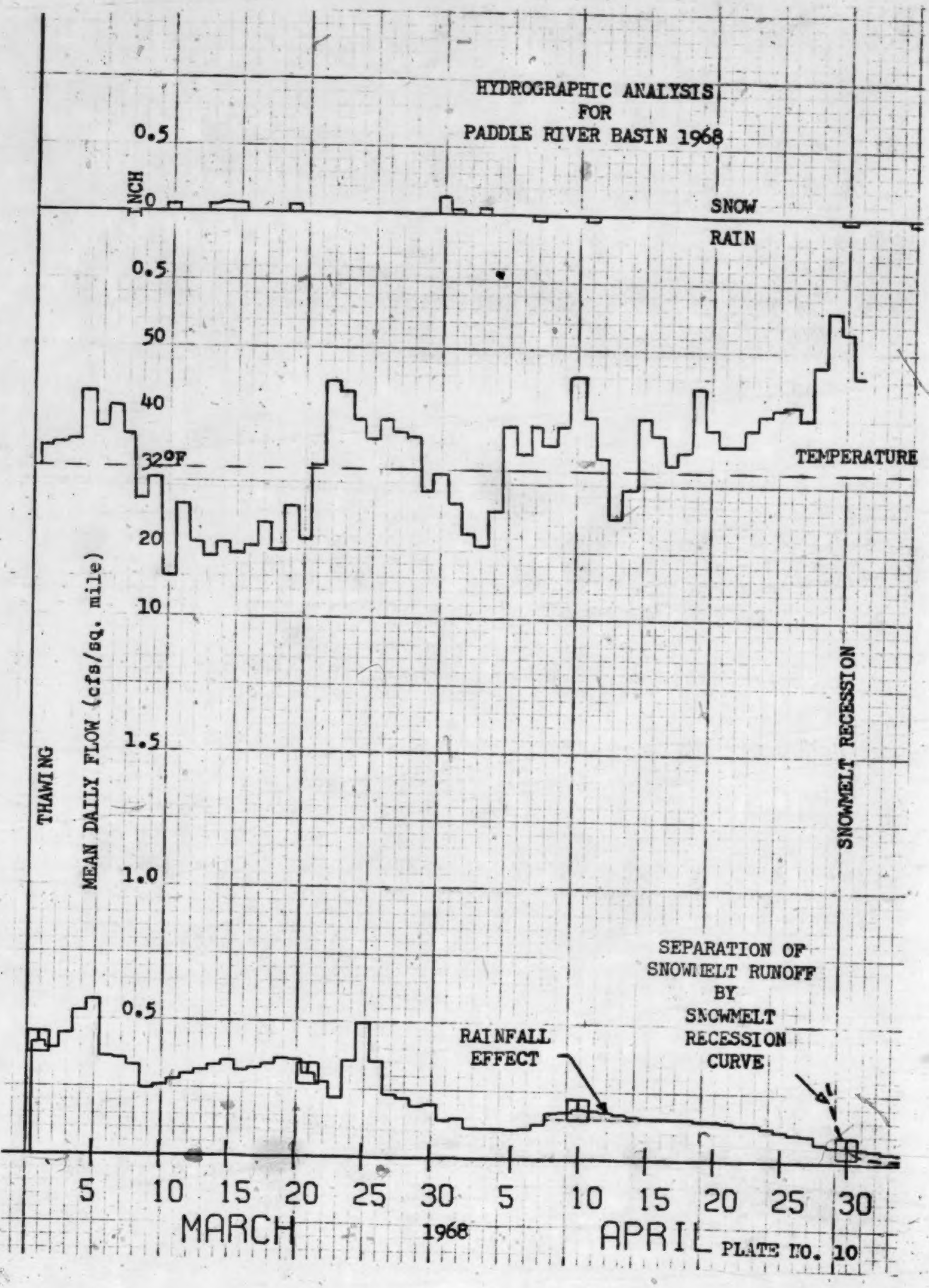

HYDROGRAPHIC ANALYSIS
FOR
PADDLE RIVER BASIN 1967
0.5
INCH
0
0.5
SNOW
RAIN
60
50
40
32
°F
20
TEMPERATURE
THAWING
SNOWMELT RECESSION
MEAN DAILY FLOW (cfs/Sq. mile)
1.5
1.0
1.5
SEPARATION OF
SNOWMELT RUNOFF
BY
SNOWMELT
RECESSION
CURVE
RAINFALL
EFFECT
25
30
5
10
15
20
25
30
5
10
15
20
25
30
APRIL
1967
MAY

PLATE NO. 9



HYDROGRAPHIC ANALYSIS
FOR
PADDLE RIVER BASIN 1968

PLATE NO. 10

HYDROGRAPHIC ANALYSIS
FOR
PADDLE RIVER BASIN 1969

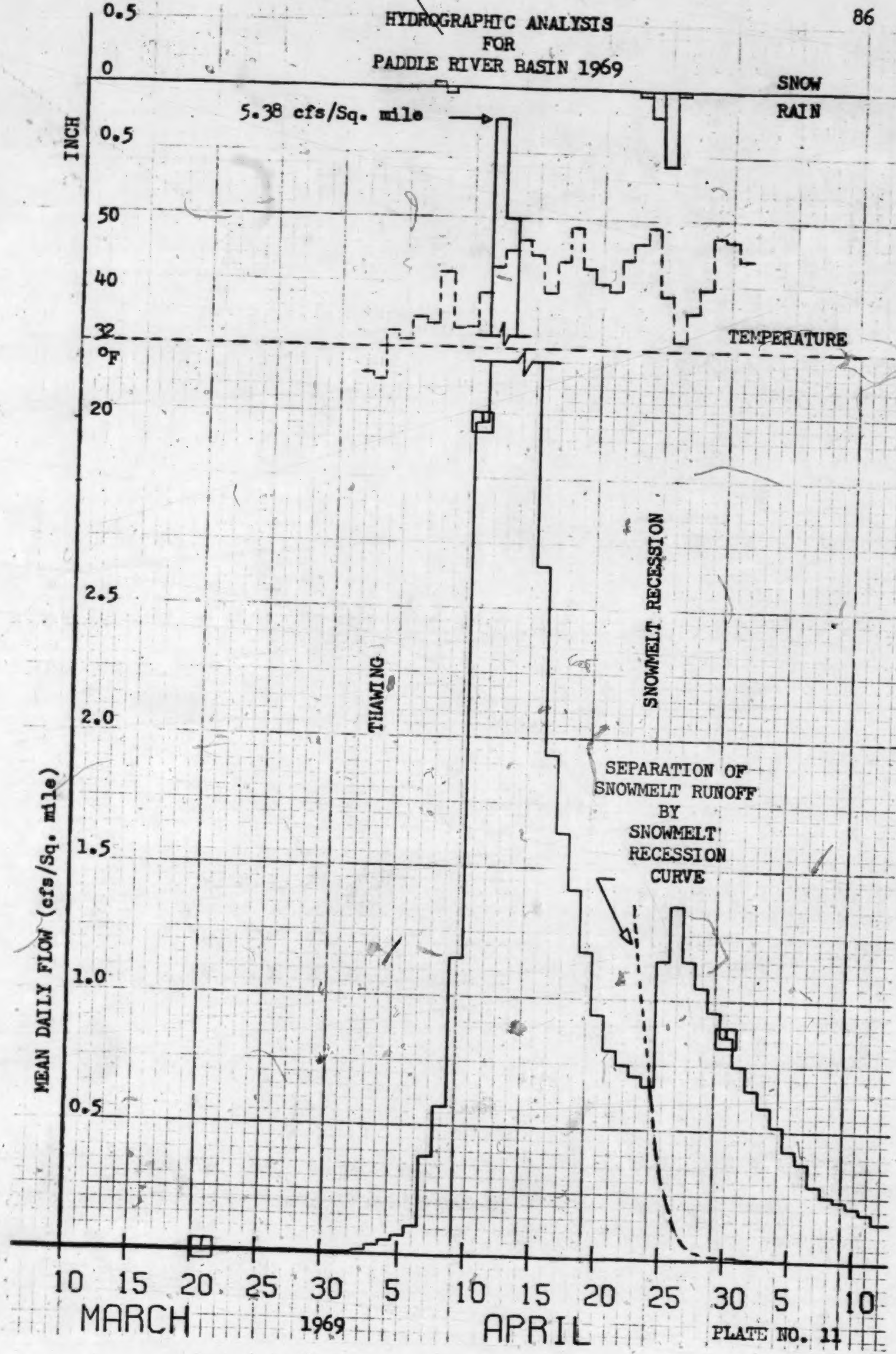
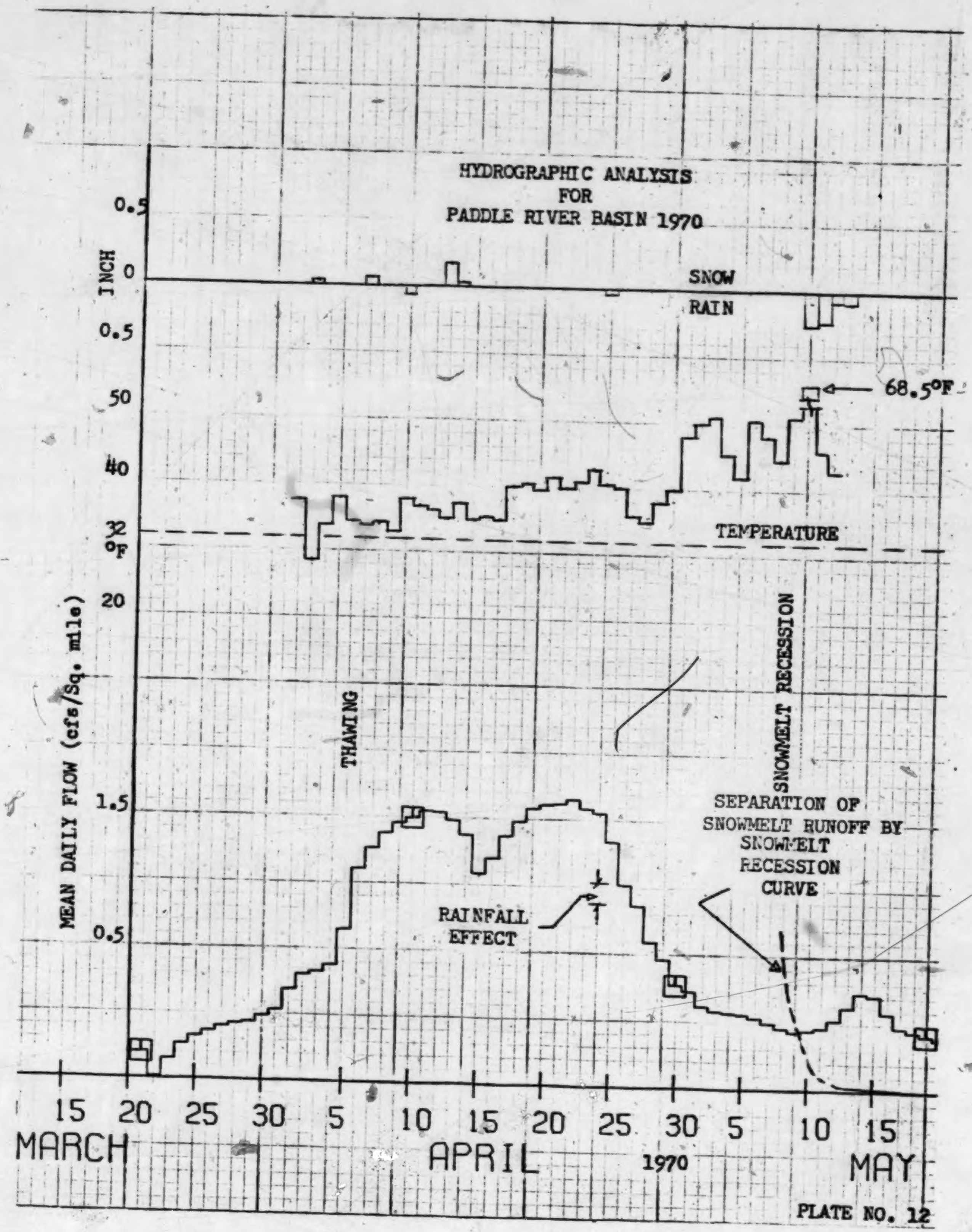
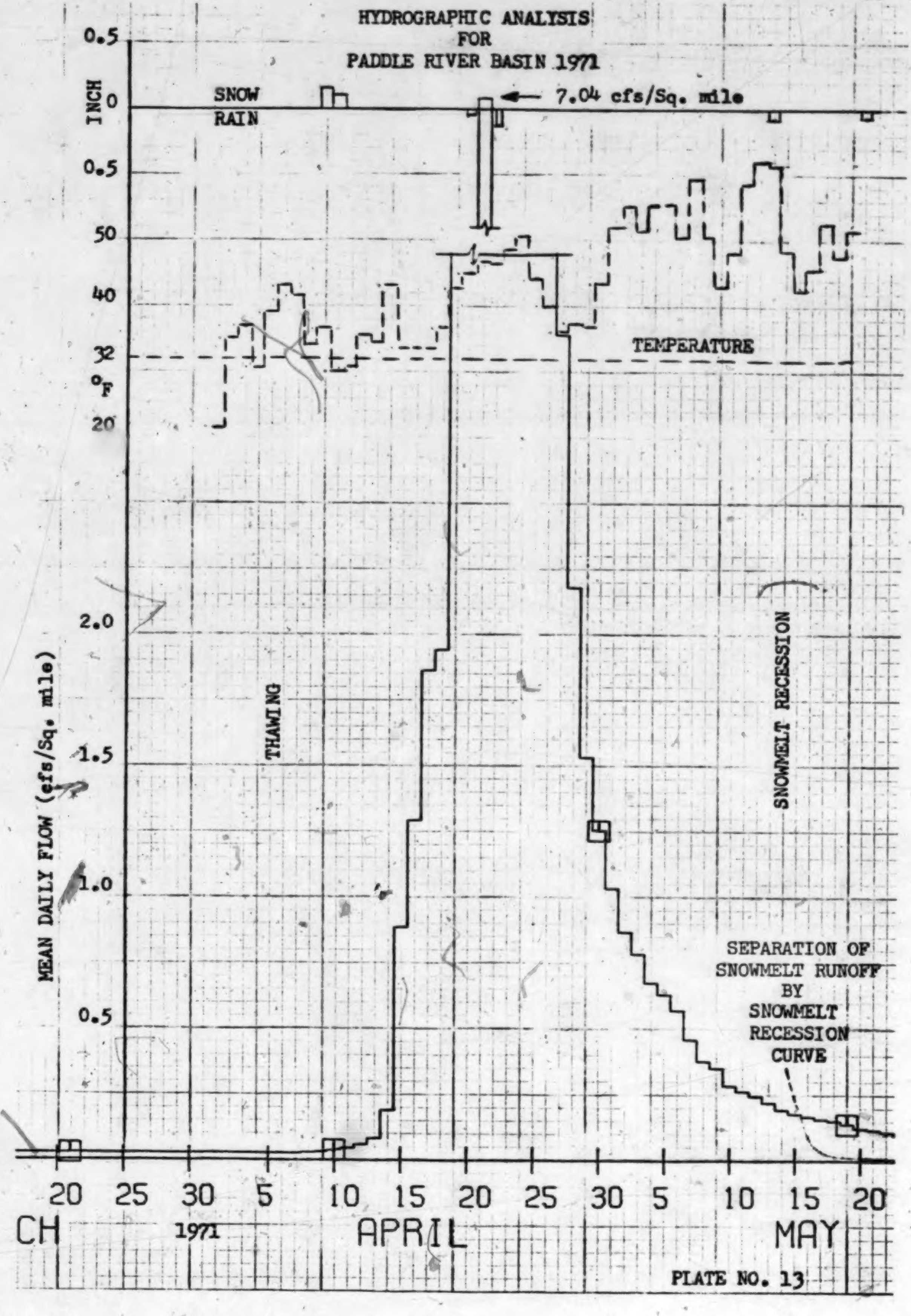


PLATE NO. 11



HYDROGRAPHIC ANALYSIS
FOR
PADDLE RIVER BASIN 1970

PLATE NO. 12



HYDROGRAPHIC ANALYSIS
FOR
PADDLE RIVER BASIN 1971

PLATE NO. 13

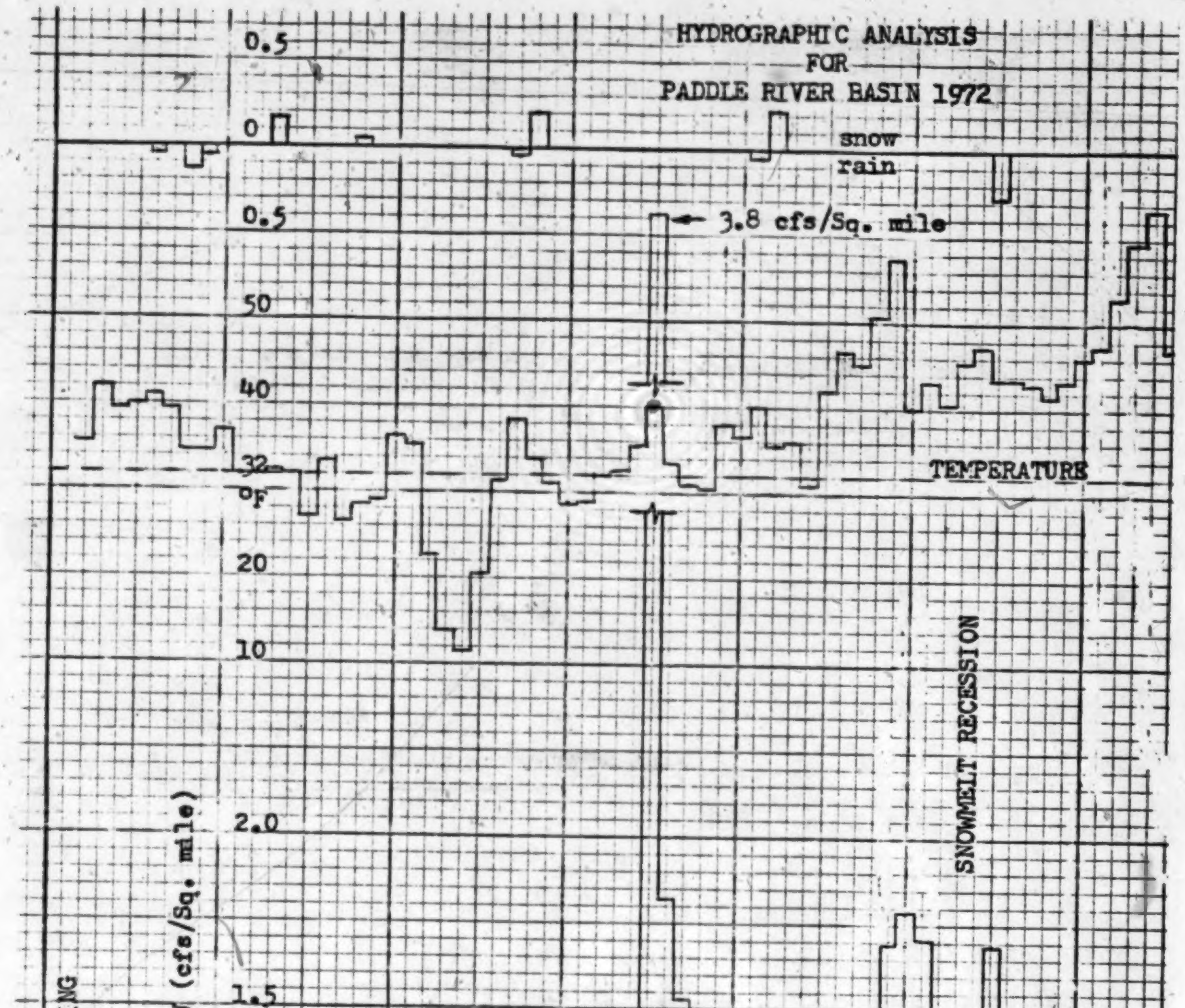

HYDROGRAPHIC ANALYSIS
FOR
PADDLE RIVER BASIN 1972
0.5
0
snow
rain
0.5
3.8 cfs/Sq. mile
50
40
32
°F
20
10
TEMPERATURE
SNOWMELT RECESSION
2.0
1.5
1.0
0.5
THAWING
MEAN DAILY FLOW (cfs/Sq. mile)
SEPARATION OF
SNOWMELT RUNOFF
BY
SNOWMELT
RECESSION
CURVE
10
15
20
25
30
5
10
15
20
25
30
5
10
MARCH
APRIL
1972

PLATE NO. 14

HYDROGRAPHIC ANALYSIS FOR PADDLE RIVER BASIN 1973

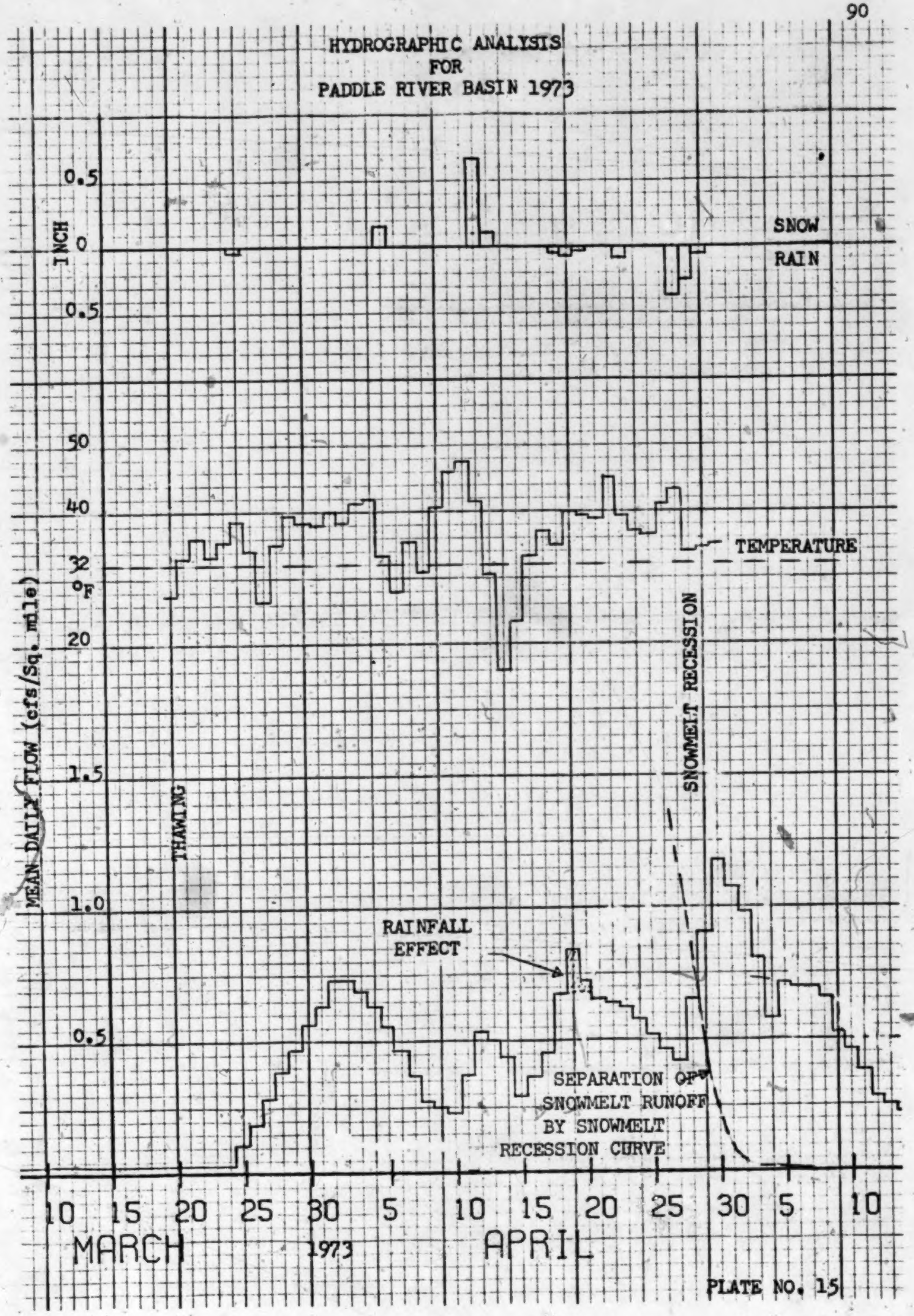
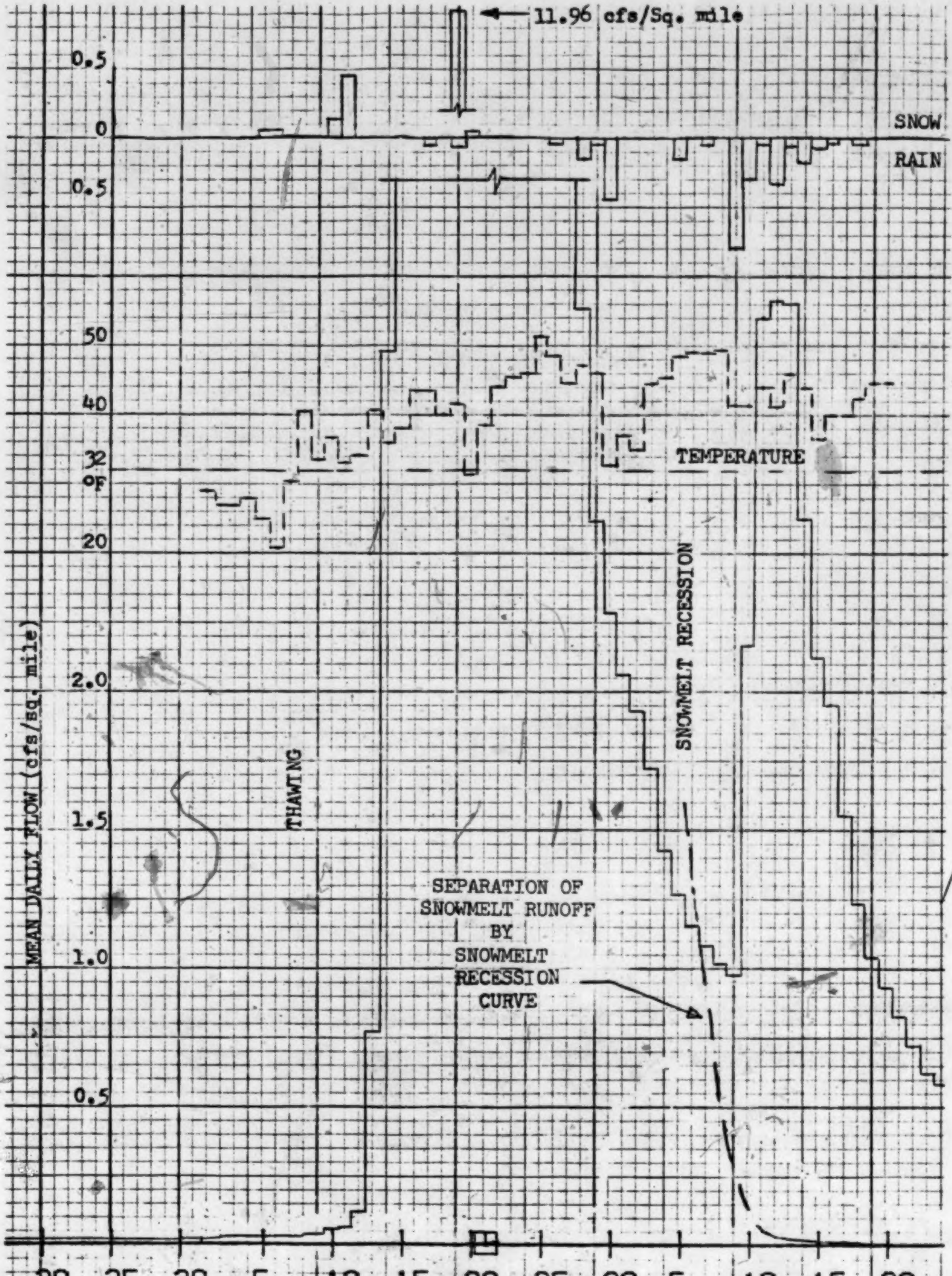


PLATE NO. 15



HYDROGRAPHIC ANALYSIS FOR PADDLE RIVER BASIN

PLATE NO. 16

SEPARATION OF RAINFALL RUNOFF FROM

SNOWMELT RUNOFF

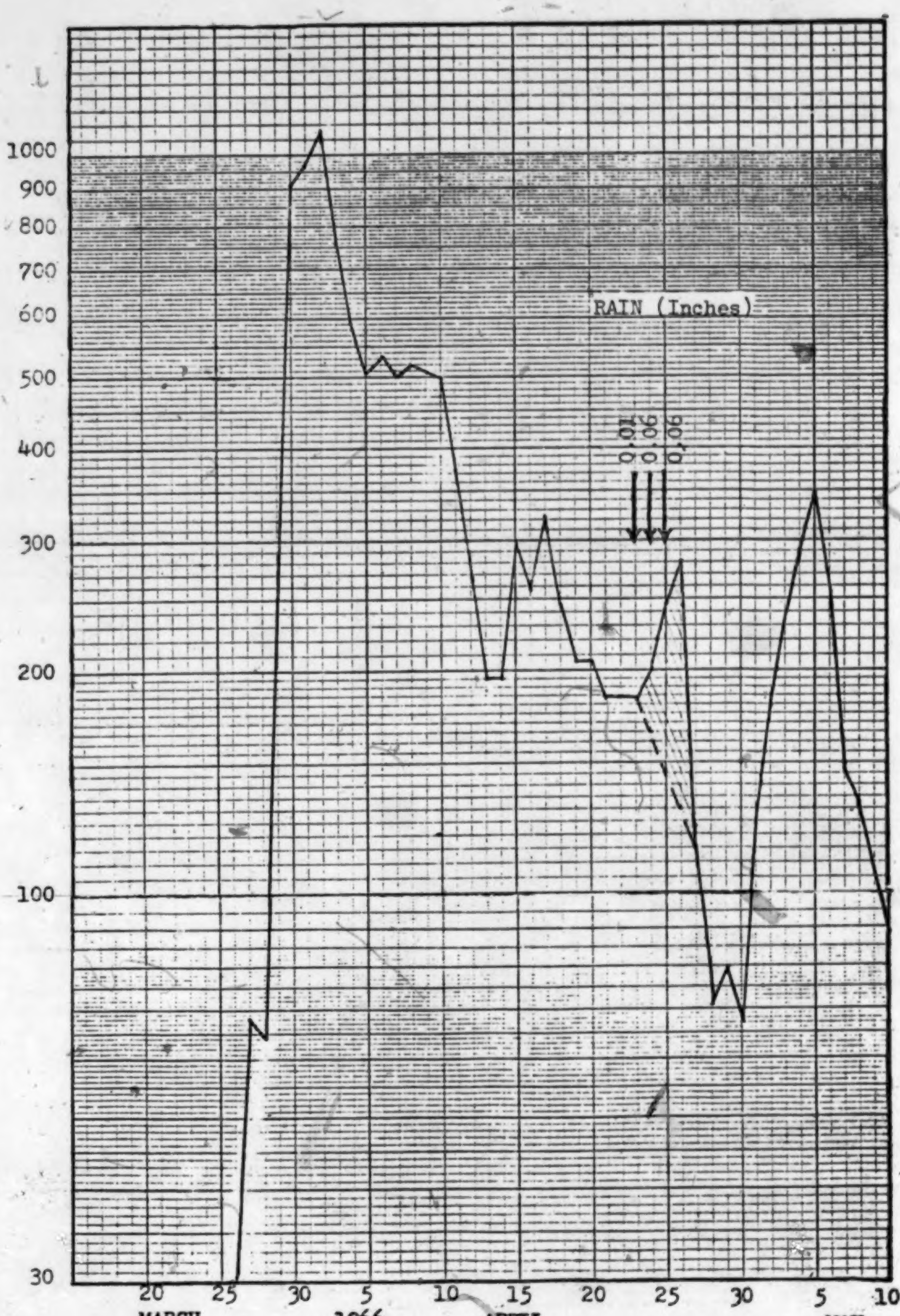
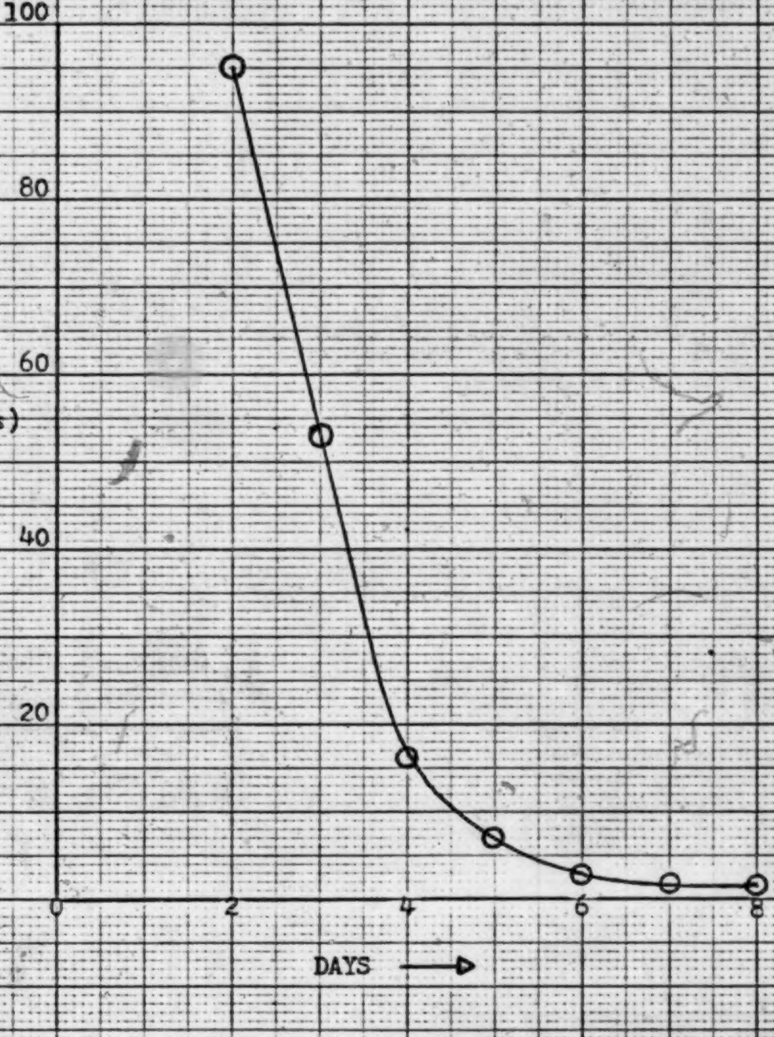


PLATE NO. 17



SNOWMELT RECESSION CURVE
FOR
PADDLE RIVER BASIN

PLATE NO. 18

K+E 20 X 20 TO THE INCH • 7 X 10 INCHES
KEUFFEL & ESSER CO. MADE IN U.S.A.
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